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No. 291

DIVISION OF AGRICULTURAL SCIENCES
UNIVERSITY OF CALIFORNIA

Economic Planning of Water Supply Systems

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GIANNINI FOUNDATION OF AGRICULTURAL ECONOMICS
in cooperation with
NATURAL RESOURCE ECONOMICS DIVISION
ECONOMIC RESEARCH SERVICE, U.S.D.A.

Giannini Foundation Research Report No. 291
May 1967

ACKNOWLEDGMENTS

This report is based on studies carried out under a cooperative research project entitled "Economic Appraisal of Irrigation Water Conveyance Systems in California," with the California Agricultural Experiment Station and the Economic Research Service, U. S. Department of Agriculture, participating. It is essentially a summary of a doctoral dissertation prepared by the author in the Department of Agricultural Economics at the University of California, Berkeley.

Professor S. V. Ciriacy-Wantrup (University of California, Berkeley) and Drs. George Pavelis and Robert Otte (Economic Research Service) served as project leaders and gave active and continuing guidance and support to the project. Professors J. Herbert Snyder (University of California, Davis), Tillo E. Kuhn (University of California, Berkeley), and Stephen C. Smith (Colorado State University) provided many helpful comments as the work progressed.

The study was greatly facilitated by members of the professional staff of the California Department of Water Resources, the Madera Irrigation District, and the Chowchilla Water District. Particular recognition is due Mr. L. B. Christianson, Regional Economist, and the staff of Region II, U. S. Bureau of Reclamation, who cheerfully and promptly fulfilled all requests for data and assistance.

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ECONOMIC PLANNING OF WATER SUPPLY SYSTEMS

by

Gary C. Taylor[1]

INTRODUCTION

Water supply for agricultural, industrial, and municipal uses is a central objective of current water resources development. Increasingly large and expensive projects are being planned and constructed for these purposes. This research has been undertaken with the objective of discerning ways by which water supply planning may be improved.

The approach is to develop an understanding of a complex problem through the identification of relevant variables in water supply development. These basic variables are then integrated into a comprehensive model based on the opportunity cost and equilibrium concepts of economic theory. This approach is somewhat broader than contemporary benefit-cost methodology in that the supply system is defined to include the physical, administrative, and institutional structures involved in the conveyance of water, in both the locational and temporal sense, for beneficial use.

The concepts, comprehensive model, and economic relationships developed in the first chapter are used in analyzing the planning and performance of the Madera Canal development in the California Central Valley Project. The Madera Canal was chosen as a case study because it has a long and interesting history of planning under local, state, and federal leadership. The system serves a large irrigated area and has 20 years of detailed operational data. Salient strengths and weaknesses of the Madera experience are analyzed with respect to their value as empirical lessons for other water supply planning efforts.

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[1] Agricultural Economist and Chief, Environmental Economics Branch, Natural Resource Economics Division, Economic Research Service, U. S. Department of Agriculture, Washington, D. C. This report was based on a dissertation submitted in partial fulfillment for the Ph.D. degree in Agricultural Economics, University of California, Berkeley.

The term "design" is used interchangeably with planning in this presentation. Design is the systematic evaluation and formulation of plans for new or revised structures: physical, administrative, and institutional. Rapidly advancing technology and constant experimentation with institutions have greatly increased the flexibility with which solutions of water supply and conveyance problems may be approached. This very complexity has increased the area of decision making delegated to the professional planners--engineers, economists, administrators, and lawyers--in their task of designing a limited number of alternative plans for policy decisions. Therefore, the analysis strives to be both positive and comprehensive in its approach and to consider the planning process as it must operate in practice.

CONCEPTUAL ANALYSIS OF WATER SUPPLY PLANNING

A Theoretical Framework for the Economic Design of Water Supply Systems

The broad and comprehensive emphasis of this study is implied in the choice of the term "system." It is intended that the planning decisions should be revealed as having actual or potential implications for all components of the water supply system. The system is defined to include not only physical components but also the administrative, legal, and other institutional structures required to supply water for beneficial use. In adopting a more comprehensive viewpoint, many of the economies and diseconomies resulting from planning decisions are internalized and their implications made more explicit.

The Basic Water Supply Model

Most water supply systems may be segmented into five major operations. In planning for water supply development, each operation should be investigated, evaluated, and integrated into a comprehensive physical plan. The first operation is the development of the sources of supply and/or storage facilities. The development may be a diversion from a surface water source, a reservoir on a stream, or a well tapping an underground source. Sources may vary in degree of control and certainty from a large reservoir, lake, or ocean source to natural runoff or an imperfectly known underground aquifer (Figure 1).

The second operation is a transportation or conveyance link moving water from a source to a point of use. The conveyance link may be a canal, a pipeline, or a less common means of transport, such as tank cars, trucks, barges, or even on a human head. Conventional conveyance systems in the United States vary in complexity from natural channels or simple ditches to paved river-large canals that may include transportation in both horizontal and vertical directions and the use and recovery of energy in pumping and generating stations. It is interesting that, in spite of the complexity characteristic of many modern conveyance systems, the initial conveyance link is usually the operation for which the most accurate performance estimates can be made.

From the viewpoint of the economist, the basic (third) operation in the supply system is utilization where water is put to beneficial use in production

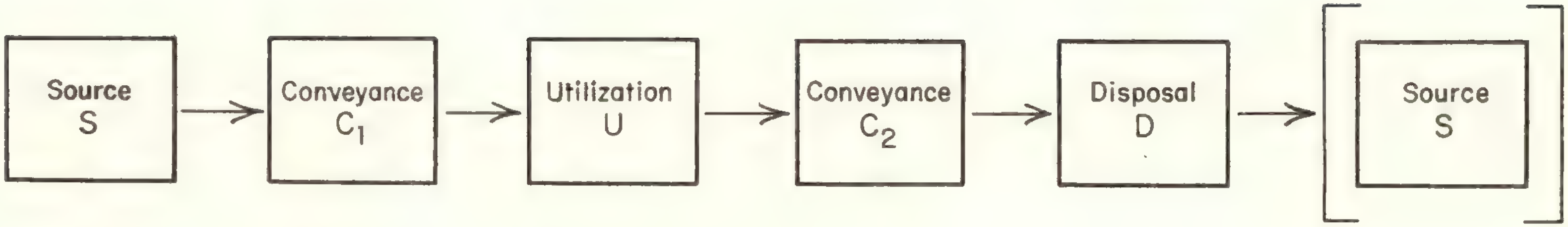

Figure 1. Schematic Diagram of a Water Supply System

or consumption. The characteristics of demands for water vary among uses and over time, both periodically and through the planning period. Shifts in population and economic activity are the two basic determinants of change in the quantities of water demanded.

The fourth operation in the supply system is a second conveyance link. In most uses, water performs a service such as absorbing heat, acting as a solvent, or transporting waste. The liquid state is seldom completely changed; therefore, water once utilized must be moved away from the points of demand. In urban areas this link is the sewerage system, while in irrigated areas it is the natural drainage regimen as it may be supplemented by tiling, ditches, pumps, and canals.

This second conveyance link has often been ignored or given inadequate treatment in the design of supply systems. Dramatic examples of this oversight are occasionally seen in irrigation projects.1/ Drainage evaluation is an important aspect of irrigation planning because inadequate drainage will result in a serious loss of soil productivity due to swamping or increased soil salinity.

The fifth operation is the disposal of water after it has drained or been conveyed away from the point of utilization. Water utilized by one supply system may enter the source of another supply system or, in the case of a groundwater basin, perhaps the same supply system. Disposal may have a quantitative impact in affecting the quantity, location, and timing of a subsequent source, and the characteristics of disposal waters may have a qualitative impact on subsequent use. Physical and chemical pollution is a serious economic problem in many areas.

This basic model of a water supply system is comprehensive in application to water supply problems involving diverse combinations of techniques to accomplish the task of supplying water for beneficial use. As mentioned, each operation does not have economic content in all cases. The development of a water supply for irrigation may not require construction of a drainage system because the natural drainage regimen is adequate and drainage costs

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1/ For a discussion of a serious drainage problem, see Columbia Basin Project Board of Consultants, Report to the Secretary of the Interior: Re Repayment Problems, Columbia Basin Project, U. S. Bureau of Reclamation, August, 1961, 33p.

or productivity losses are not induced on benefited or other lands. In a similar fashion, the disposal of used or waste waters may have no economic impact upon the quantity or quality characteristics of other water sources as, for example, treated sewage outflows to the ocean.

The utility of this basic water supply model is that it may serve to guide the formulation of a comprehensive investigation. Potential sources of bias or omission can be precluded by an imaginative examination of the movement of water through the supply system. Unless the potential impacts and the economic relationships between operations are considered, the resulting plan will be most desirable from the viewpoint of its comprehensive economic impact only by chance.

Economic Dimensions of the Planning Problem

Planning for water supply, as with other economic problems, is characterized by dimensions of demand, supply, location, time, and quality. A basic characteristic of water supply systems is the spatial separation of the sources of supply and the points of demand. The function of water conveyance is to move water over distance from points of low-value use to points of higher value use. This distance is represented in the basic model by the first conveyance link (C_1).

Location of Water Conveyance Systems.--The basic objective of planning water conveyance systems is to bring about new spatial and temporal patterns of water utilization that maximize benefits to the relevant economy over the costs and losses involved in doing so. The spatial perspective of the planning problem is clarified by relation to theories of location and spatial economy involving the total spatial array of economic activities and the resulting geographic variation in prices and costs.[1] Prices and costs vary within a given area due to variations in natural resource endowments and patterns of subsequent economic development. Sources of water, for example, occur in natural channels or underground basins at varying distances from the points of actual or potential demand, such as population clusters or arid but potentially productive soil resources.

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[1] Walter Isard, Location and Space-Economy (New York: John Wiley & Sons, Inc., 1956), p. 53.

The basic concept of spatial economics is substitution between inputs. The major emphasis, of course, is on the substitution of transportation for other inputs. If water is conveyed from a low-cost source with a resultant supply price that is lower than local supplies, conveyance costs or transportation inputs have been substituted for local water supplies. The availability of lower priced water will induce substitution between factors of production or commodities of consumption that result in the use of more water per firm or household. Thus, the substitution phenomenon at a particular location occurs in two ways: (1) a substitution of low-cost water for high-cost water and (2) a substitution of water for other factors of production; i.e., land, labor, or capital.

When the costs of water are lowered, the competitive advantage of the area as a site of production and as a place to live is improved. A substitution of locations will occur. The benefited area will be substituted for competing areas to some extent. Construction of a water conveyance system providing lower water supply costs creates a disequilibrium situation. The adjustment in the service area may be visualized as a shift of the composite water demand function to the right as substitutions among factors and commodities and substitutions among points of production and consumption occur. The resulting long-run spatial equilibrium pattern results in an increase of net benefits to the society through lower costs of production and increased satisfaction, assuming that significant induced adjustment costs borne by competing areas have been included in the analysis.

The concept of a marketing area: Conceptually, the location of a conveyance system and thereby the delineation of water service areas is the choice of a marketing area for water. For the moment, we will be concerned with only the first three operations of the basic water supply model; that is, the source, first conveyance link, and point of use.

Total transportation cost is an increasing function of distance. Thus, within a given technology or group of production functions, the real cost per unit of water (supply price including transportation cost) will increase with distance from the source. The opportunity cost of the conveyed water rises, and it becomes less competitive as an alternative to existing or potential supplies with increasing distance conveyed.

The simplest possible case for a water marketing area, the classic von Thünen model, would be a well surrounded by an arid plain over which potential consumers, each having similar demand schedules, uniformly distributed the water.[1] Assuming a given level of technology--a hand pump and men with buckets--the water would be sold in equal amounts on any direction vector. The water price would include a fixed pumping cost plus a conveyance cost increasing with distance. Lines of equal supply price, isotims, would be concentric circles about the well. The water marketing or service area is defined by the highest supply price consumers are willing to pay for the first unit of water. In other words, the market area includes all consumers who will buy water from this source.

A cheaper but less flexible technology is introduced. A canal is dug in one direction from the well. The supply price is lowered in the vector of the canal, and the isotims are distorted in this direction. New consumers are brought into the market, and a larger total quantity of water is sold. The quantities delivered from each point along the canal are a decreasing function of distance from the well.

If a second well is developed near the canal, the situation is more complex. Assume the pumping cost at the second well is higher. Consumers served by the first conveyance system but near the new well may find that the supply price at their location is now lower from the new well. The relevant market of the first system is no longer regular, and the deliveries from the canal are no longer uniformly decreasing over distance.

An important factor in transportation costs is the physical topography traversed. The real costs for given distances may be very different. The canal in our example may require a tunnel that abruptly increases the real transportation cost beyond it. The transportation cost is no longer a smoothly increasing function of distance.

The above situation is illustrated in Figure 2. There are two sources of water, A and B, and two technologies of conveyance. The area represented is a uniform plain interrupted by a high, narrow ridge. It is assumed that isotim 10 represents the location of consumers who are willing to pay for the first unit of conveyed water from either source. Market area A includes all

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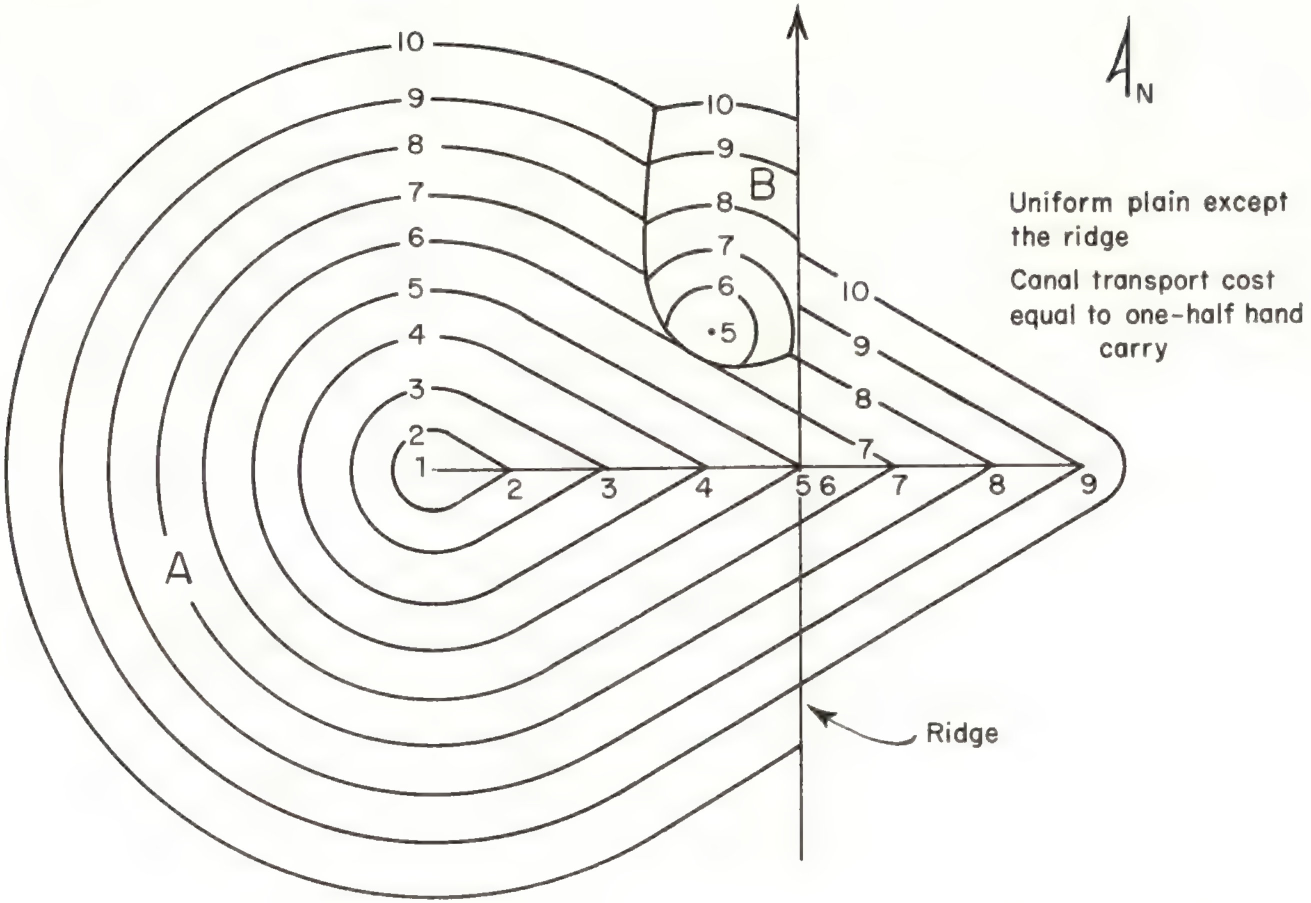
[1] Johann Heinrich von Thünen, Der isolierte Staat in Beziehung auf Landwirtschaft und Nationalökonomie (Hamburg, Germany, 1826), 678p.



Uniform plain except the ridge

Canal transport cost equal to one-half hand carry

Figure 2. Theoretical Market Areas (Map of Equal Water Supply Prices)

consumers who are prepared to purchase water from source A. The boundary between market areas A and B represents purchasers who are indifferent as to source because they are faced with equal supply prices from both sources. We have assumed that all demand schedules are identical. Therefore, the greatest use of water per consuming unit will occur in zone 1-2 and the least in zone 9-10.

Of course, our example is highly simplified. It is assumed that supply cost is synonymous with supply price. This is seldom observed in practice.[1] In the real world situation, the physical topography is very important in the least-cost location of the conveyance system. More important, the heterogeneous distribution of resources, natural and cultural, results in a heterogeneous distribution of potential water consumers, and further, there is a great variation in the demand schedules for water between consuming units.

This example illustrates a phenomenon observed in reality. Water from source B is supplied for short distances in southerly and westerly directions, while the canal from source A passes it on the south in an easterly direction. This results from variations in the price-cost surface. In actual situations it may result from costs, organizational boundaries, or ownership of water rights. The movement of water supplies in opposing directions is not necessarily illogical, given the original planning situations.[2] As conditions change, consolidations of districts or transfers and exchanges of service points or water supplies, with accompanying reorganizations of physical systems, may result in increased benefits. Failures to adjust to changing conditions may lead to serious diseconomies. This problem, of course, is not limited to water supply systems.

Implications of Water Quality.--The economic significance of water quality depends on the physical, chemical, or biological specifications of demand. A particular supply may be ideal for one use and entirely unsuitable for another. The relevant marketing area for a source of mineral water, for example, may be radically different from that of a nearby river. Supplies of high quality, and thus high value, may incorporate proportionally higher transportation cost and be conveyed over longer distances than competing sources of lower quality in meeting given demands. This is a fundamental principle in transportation economics.

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[1] See discussion, *infra*, pp. 35-36.

[2] See comments on the Madera Canal and East Side Division of the Central Valley Project, *infra*, p. 85.

Very often water from a common source may be supplied to all the relevant demands. The question of quality then is relative rather than absolute and is reflected in costs of source development, conveyance, or utilization. Costs may be incurred to regulate or change the quality characteristics of supply to meet various demands through sedimentation, desalinization, chlorination, softening, etc. Costs may be incurred by the consumer before the water is used, which in turn shifts his demand schedule to the left as other inputs are substituted for water.

There are important economies in the use of large-scale treatment plants before water is delivered, but the detailed regulation of quality to meet a variety of specific demands would be very complex. Households want softened water; irrigators do not. Cooling processes demand cold water, and boiler systems demand warm.

Induced Costs and External Effects.--The discussion thus far has focused on the first three operations of the supply model, source development, conveyance, and utilization. The supply cost at the point of use is the sum of the development and conveyance costs. If the supply cost is equated with the supply price and related to the demand schedule, the quantity demanded is determined in a static sense. However, the provision of a conveyed supply has induced added costs for drainage (C_2). These also are a cost of the system, whether they accrue to the direct consumers or to others and should be considered. Further, if the water leaves the drainage link to be disposed of in the sources of other supplies, the effects will be to augment these sources quantitatively and to upgrade or downgrade the sources qualitatively. Thus, inclusion of the drainage costs (C_2) and costs and benefits of the disposal operation may radically affect the quantity of water which maximizes the net benefits of the system.

The comprehensiveness of the basic model permits consideration of these induced costs and benefits as internal to the planning problem. Changing the value of planning variables in one operation often includes changes in the value of variables in other operations. For example, if water could be supplied to an area for irrigation development at a very low price, the irrigators would be expected to adopt an irrigation technology that was efficient economically but wasteful in a physical sense. A large drainage outflow might in turn cause serious swamping or salinity problems in neighboring areas.

An agency capable of comprehensive action could attack both problems by raising the supply price to the farmers in the first area, reducing their demand for water and inducing them to adopt an irrigation technology which required less water, i.e., substitute other inputs for water. This in turn would reduce the drainage outflow and the induced costs of drainage structures in the second area. The objective of the agency would be to maximize the net benefits to the entire area of influence of the system. Revenues over costs received from water sales in the first area might be used to pay for induced drainage costs in the second area, but this is separate from the problem of adjusting all variables of the system to maximize net benefits.

Time as a System Dimension.--Water supply systems are usually intended to provide service over a long period of time. The physical structures are generally capital intensive; that is, the bulk of system costs accrue at the time of construction with relatively minor administrative and operational costs accruing in later time periods. The major benefits, however, accrue in later time periods often at increasing rates.

The potential returns from the same capital in alternative investments of similar risk determine its opportunity cost, i.e., the discount rate. This percentage, representing the economic cost of time and risk, is used in planning computations to adjust the projected benefits and costs accruing in different time periods to a common time period for the consistent evaluation of alternative systems.[1/]

There is considerable variation in the durability of supply system components. There is also variation in the durability of structural components as, for example, a large reservoir versus an unlined canal or drainage ditch. Furthermore, unforeseeable changes in the location, amounts and characteristics of demand, supply technologies, and institutional and administrative components of the system may render the physical structures economically obsolete before they are worn out.

[1/] For the logic and mathematics of investment theory, see:

Friedrich A. Lutz and Vera C. Lutz, The Theory of Investment of the Firm (Princeton: Princeton University Press, 1951), 253p.

E. L. Grant, Principles of Engineering Economy (3d ed.; New York: Ronald Press Co., 1950).

Otto Eckstein, Water Resource Development: The Economics of Project Evaluation ("Harvard Economic Studies," Vol. CIV; Cambridge: Harvard University Press, 1958), 300p.

Due to the inherent uncertainty of planning, an evaluation period, shorter than the expected life of the structures and often termed the "economic life" of the project, is generally selected. The determination of the evaluation period is a subjective decision which should be based on the individual alternatives considered; i.e., significantly different evaluation periods may be justified for alternative potential systems on the basis of projections of the major variables and relationships over time. The problems of planning over time and uncertainty are further considered.[1]

Empirical Considerations in Supplying Water

In this section, the basic model will be detailed to include important empirical aspects of the water supply planning problem.

Periodic Fluctuations in Supply and Demand.--Surface water sources are usually subject to significant variation in runoff flows on a seasonal and even a daily or hourly basis. These fluctuations may have an important impact on the costs per unit of supply. Demand schedules of consumers are also usually subject to periodic shifts. For example, the demand for irrigation water may be zero in the dormant season regardless of the supply price. In urban areas the seasonal shifts are less pronounced, but emergencies such as fire fighting may induce abrupt increases in demand.

The value of water or the supply price that could be charged is highest during periods of peak demand, such as midsummer irrigation periods. If peaks of water demand and flow at the source coincided, the conveyance system could simply be designed to provide adequate peaking capacity. Usually, however, storage must be provided at the source or along the route of conveyance. Thus, a combined storage-conveyance system is designed to carry water over both time and distance. Storage involves another cost of supply that is reflected in the real supply cost of water at the place and time demands are met.

Economies of Size.--Systems for water conveyance involving canals and pipelines are characterized by economies of size; that is, generally the larger the capacity the lower the cost per unit of capacity. However, the transportation cost per unit of water depends on the volume of units actually conveyed. A large conveyance structure used at partial capacity may result in a very high transport cost per unit.

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[1] Infra, p. 32.

The source development and storage components of the supply system exhibit varying cost relationships depending on rates of use and technology employed. Surface storage costs per unit depend on the quality of natural sites available; i.e., the topographic configuration, amount and timing of runoff, and the geological conditions of the dam site, but not necessarily on the size of the reservoir.

The direct supply cost of water depends on the source and storage costs plus the conveyance cost. The quantity of water to be marketed from the supply system depends on the demand schedules of the consumers at the locations served. The amount demanded and the locations of demand in turn determine the costs of development, storage, and conveyance. Hence, the location and sizing of the supply system are conceptually interrelated.

Integrated Planning of Ground and Surface Water Supplies.--Relatively recent developments in pumping technology have stimulated the exploitation of groundwater aquifers for water supply. Subsequent depletion of these aquifers has led to increasing supply costs and the creation of large amounts of empty storage capacity.1/ Groundwater aquifers have two important characteristics relevant to conveyance planning. First, they provide the potential for a relatively dependable storage capacity already tapped by pumping systems over large areas. Second, naturally occurring interconnected aquifers are a natural conveyance system. They may further provide the potential for infiltration and storage for reuse of drainage waters from irrigated fields. Thus, underground aquifers provide a potential to replace surface storage capacity and conveyance capacities (both C_1 and C_2) that would otherwise be required under a particular set of demand and supply relationships.

The presence of groundwater aquifers that are feasible to recharge underlying a potential market area is particularly important with respect to the periodicity of supply and demand relationships and short-run inflexibility of water conveyance facilities; i.e., when water is not being transported, the facilities cannot be used to transport something else. During the off-peak demand periods, conveyance facilities may be used to transport water from

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1/ R. L. Leonard, Integrated Management in Ground and Surface Water in Relation to Water Importation: The Experience of Los Angeles County, University of California, Giannini Foundation Research Report No. 279 (Berkeley, 1964), 90p. This is one of a series of Giannini Foundation groundwater studies.

surface reservoirs to underground aquifers. Thus, the underground aquifers are substituted for the surface reservoirs to store water for supply at the time of peak demand. Therefore, the demand for supplies from the surface conveyance system may be reduced during peak periods. The integrated supply system permits reduction in the capacities of surface storage and conveyance systems, thereby reducing costs.[1]

Joint Production in Water Resource Systems.--Modern water supply systems are typically planned to produce multiple products. Joint production may include electrical power, flood control, recreation, and other services as well as water supplies. The optimum combination of outputs does not permit the maximization of all individual purposes. The generation of hydroelectric power by a reservoir power plant affects the timing of releases to the water conveyance systems at the reservoir site or downstream from it. In such cases, the conveyance system design may be altered to make optimum use of the changed pattern of water supply. These alterations may be considered a cost of power production. However, the situation further illustrates the interrelatedness of water storage and transportation.

The conveyance of water requires energy to overcome the "friction of distance." In gravity flow systems, the energy is provided by the initial evaluation of the water. In other systems, the energy is introduced by pumps. In either case, sometimes energy may be recovered from the conveyance system by the hydroelectric generation. Joint production may be a significant consideration in the development of the water source and in the transportation of water both in terms of different quantities of water supply and in terms of substitution between water supply benefits and those from other types of water services.

Decentralized Decision Making Within the System.--The water supply system includes not only the naturally occurring resources (water and dam sites) and physical structures (dams, canals, and drainage systems), but it also includes management--decision makers in government, firms, and private life. The discussion of the basic marketing model indicated two groups of decision makers--the planning agency engaged in comprehensive planning and consumers.

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[1] The integration of conveyed and local groundwater supplies was a central consideration in planning the Madera Canal system, infra, pp. 49.

In the development of large-scale water supply systems in the West, and particularly in California, the planning and construction agency, whether the Bureau of Reclamation, the State of California, or the Metropolitan Water District of Southern California, has sought to limit water deliveries solely to public districts who in turn deliver to consumers. The larger agency may be thought of as "wholesaling" water to intermediate districts who in turn "retail" the water to the ultimate users.

The development of a hierarchy of distribution complicates the comprehensive approach to planning because it becomes more difficult to estimate the ultimate reaction of the consumer to the conveyed supply of water.[1/] The policies of interaction between the district and the wholesaler and the district and the consumer must be known or estimated before maximization of net benefits to the entire system is possible. To illustrate simply, demand analyses will be in error if the wholesaling agency estimates the quantity of demand at the consumer level, based on an assumption of tolls, when the subsequent policy of the intermediate district is to distribute the water without tolls and to finance supply costs through real estate taxation. In Figure 3 the basic model is differentiated to illustrate a hypothetical master water supply agency wholesaling water to a public district that retails it to an irrigator. Note that the conveyance links, including drainage, are segregated into three levels of decision and that the district has developed a water source independently.

The Comprehensive Planning Model

In the previous sections, the basic physical supply system, the economic dimensions, and the major empirical complications of the water supply problem have been considered. In this section, the marketing area concept is expanded to provide a comprehensive framework for planning the development of water supplies. The economic constructs and relationships are based on opportunity cost and equilibrium concepts. The planning objective is the maximization of net benefits. Administrative or institutional structures may be introduced as constraints initially or in later stages of the planning process. However, during the planning process, these structures are usually somewhat flexible, and modifications of these constraints should be evaluated also.

[1/] See Madera case study, *infra*, p. 78.

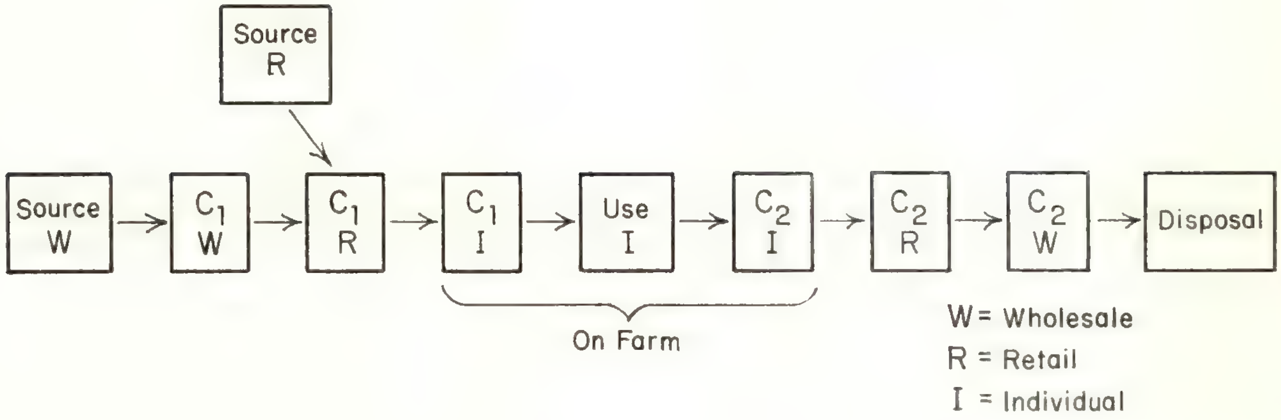

Figure 3. Hypothetical Irrigation Water Supply System Involving a Wholesaling and Retailing Agency

Given an initial source of water, the marketing area is expanded until the incremental cost of supply is equated with the incremental benefit or incremental costs of alternative supplies at every point of demand. All other points of demand are outside the marketing area and the maximizing objective is achieved in the static sense.

Schedules of demands, either as price-quantity or as benefit-quantity relationships, are subject to periodic fluctuation within a time period (e.g., day or year), and they may be subject to shifts over time. It has been stressed that the specifications of demand determine the quality characteristics of supplies that will be utilized.

The supply side of the planning or marketing problem includes all components of the system except the point of utilization. The comprehensive approach requires evaluation of all costs and benefits resulting from source development, conveyance to and from the point of utilization, and the disposal of outflows from the system. Often some segments of the supply system are excluded in the planning process. However, all components of the system should be analyzed as to their relevancy in each situation. For example, if a farmer conveys water from the canal headgate to the fields irrigated or maintains a drainage system to his farm boundary, these operations are conceptually a part of the supply system. The economic and institutional environment within which the farmer operates provides the incentives for changes in the physical efficiency of his water use through investments in his part of the supply system or through more skillful irrigation management. These changes by individual farmers may have a significant aggregated influence on the effectiveness of a large irrigation water supply project over time. On-site industrial water treatment (e.g., cooling or purification) is also a part of the supply system as are decisions between individual and centralized water softening facilities.

Comprehensive consideration of the water supply problem includes external effects of the system, e.g., from drainage and disposal operations, as well as the induced effects mentioned above. Thus, a comprehensive supply plan involves the linking of a water source with a point of utilization and conceptually includes all the effects of doing so from the development of the initial source to the entry of outflows from the system into subsequent sources. All components of the system are considered variable in the planning stage. The formulation of the final plan involves adjusting those variables that must be fixed in getting the system into operation so as to maximize net benefits over the economic life of the system.

The key variable in the system is the specification of demand. The benefit-quantity relations at the points of demand must be known or estimated. The specifications of quality, periodicity, and trends during the life of the system must also be estimated.

The second major variable is the supply schedule for water that meets the location, time, and quality specifications of the demands. The supply cost-quantity relationship includes all economic effects of the system. The incremental supply costs should be suitably increased or reduced through the inclusion of induced or external benefits and costs. Equilibration of incremental benefits and costs through the increase or reduction in the quantity of water supplied to each point of demand maximizes the system.

Empirical determination of demand and supply schedules, suitably credited with induced and external effects, for each potential point is obviously out of the question. The problem is best handled by aggregation into the smallest feasible areal units. Equilibration of incremental supply costs and incremental benefits can be approached through successive approximations using simulated systems. The analysis is iterative, proceeding from initially crude estimates of the demand and supply schedules through progressively refined estimates for narrowing relevant segments of the relationships.

The comprehensive approach using the iterative planning process is complicated in cases where the supply system is one feature of a multiple-purpose project. For example, provision of water supplies from a surface reservoir may be competitive with power production or recreation. The conceptual approach is the same. The incremental benefits for various outputs and incremental costs are equated. The maximization of the reservoir project alone is a partial solution that yields a useful first approximation. The final maximizing solution is gained by the inclusion of other outputs produced at the reservoir as parts of the water supply system and making indicated adjustments in all variables.

There is a similar problem in the adjustment of the system to integrate conveyed and local surface or groundwater supplies. The procedure is to include these supplies as a part of the proposed supply system, to obtain a maximizing solution, and then to seek to design the physical and institutional environment that will bring about this solution.

One of the most difficult problems for the planning group is the presence of decentralized decision making in a given system, resulting in fragmentation of control over the essential variables of the system. For example, if the planning group is designing the wholesaling segments of the supply system, the pricing policies of the retailing group will be critical factors for the analysis of the quantities of water that will be demanded. Thus, maximization of the system requires estimates of the expected behavior of all variables and particularly those not subject to control after the system is in operation.

Often under decentralized control there are lags in the completion of various parts of the system. If this can be anticipated, the initial units should be staged, if feasible, to complement those lags not under the control of the main development agency. No useful purpose is served by the construction of reservoirs and main canals if other key variables of the system including, for example, distribution systems and land preparation, are not concurrently staged.

The comprehensive supply system is composed of interrelated variables in the initial planning stage. The key relationships are the demand and supply schedules at each point in the marketing or service area. The range of relevant variation is progressively reduced through an iterative process of successive simulations of the system until the final plan emerges that maximizes net benefits over the economic life of the project. Construction of the project restricts the operational flexibility of the physical structures. Institutional structures, such as contracts, restrict the flexibility of both administrative and operational policies. Therefore, because water supply systems are generally long-lived and relatively expensive, it is important to generate information during the planning process that will insure the fixation of these variables at the best possible levels.

The Economics of Major Structural Components

The purpose of this section is to: (1) present cost-capacity relationships for major physical components; (2) illustrate the economic relationship between conveyance and storage facilities; and (3) demonstrate the economies of large capacity structures, in terms of both capital and operation costs. The intent is to present some empirical relationships in water supply technology.

Conveyance Structures

Conveyance structures are used to transport water, in horizontal and vertical directions, from the natural or developed source to points of demand and to transport water away from the points of demand to disposal points. The conveyance links are composed of canals and conduits and pumping facilities.

Canals and Conduits.--The capacity of a conveyance system is determined by the maximum economic deliveries to supply peak demands. Peaking demands result in unused capacity between peaks and thus additional overhead costs per unit delivered. The economic design problem is to optimize the relation of unmet demands at peak times and unused capacity during off-peak periods. Cost of peaking capacity may often be reduced by a combination of conveyance capacity, regulatory reservoirs, and underground storage on the supply side or possibly through influencing timing of demands as through changes in the water price structure.

The optimum economic design for a conveyance system is strongly influenced by the topography to be traversed. The physical capacity of canals and conduits is determined by slope and cross-section parameters. If the slope of the conduit is steep, velocity is increased and cross-sections and construction costs are reduced. The steepness of slope or ratio of head to distance is determined by points of elevation along the route. If the natural head is insufficient, pumping head is required. In cases where natural available head is insufficient, the savings in the capital cost of increased slope are balanced against the increasing capitalized cost of pumping to determine an optimum design slope.

The construction costs of a given conveyance link are determined by the characteristics of the route considered and the points to be served. The topographic conditions of the route will determine the economic use of drainage structures, siphons, drops, tunnels, and wasteways. The geologic conditions will influence safety factors and excavation costs of canals and tunnels. Cultural characteristics will determine the costs of rights-of-way and relocations. Location and time patterns of water demand will determine the need for check and turnout structures.

Tunnels are often substituted for canals or pipelines when the topographic conditions of the route indicate that they are a more economic alternative. Tunnels are efficient substitutes to shorten the route of conveyance, lower pumping costs, or lower maintenance costs, particularly where a canal would be in deep cut or on unstable slopes. There are considerable uncertainties in tunnel construction, however, due to unforeseeable geological conditions.

Pumping Facilities.--Pumping stations are included in conveyance systems to lift water over topography that cannot be crossed using naturally available head or that would require more expensive alternatives such as a tunnel or a more circuitous canal or pipeline route.

Several factors are important in selecting the most economic pumping unit or combination.1/ A range in pumping requirements, both discharge and head, may make the combination of two or more pumps desirable. The use of pumps in combination allows flexibility in operation, and the final selection of standby capacity is based on the demand for constant flow, the amount of terminal storage, variation in head, and other factors. It is generally found that the most economic alternative, in areas where water is demanded throughout the year, is to operate the conveyance system at full capacity and to provide for regulation, emergency drainage, and required maintenance shutdown through the use of regulatory reservoirs if these can be constructed at a favorable cost.2/

Distribution Systems.--The economic design of distribution systems is similar to main canals and pipelines except on a smaller scale. On federal

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1/ Much of this material was developed from text and data in California Department of Public Works, Division of Water Resources, "Procedures for Preliminary Design and Cost Estimating of Hydraulic Structures" (unpublished materials for Statewide Water Resources Investigation, Bulletin No. 3, Studies 1952-1958), 126p.

2/ California Department of Water Resources, Investigation of Alternative Aqueduct Routes to San Diego County, Bulletin No. 61 (Sacramento, 1957), p. 123.

irrigation projects it is customary to design and construct lateral systems independent of main canals because the financing arrangements are separate. Conceptually there is no difference, and the planning decisions that must be made are interdependent.

The capacity required in a distribution system depends upon the peak demand plus allowances for seepage, operational waste, and evaporation. Evaporation is usually considered insignificant unless regulatory reservoirs are included in the system. Smaller laterals must have a lower ratio of acreage served per unit of capacity in order to provide flexibility in timing deliveries.

Drainage Systems.--It will be recalled from the basic water supply model that the fourth operation is a second conveyance link moving water from the point of utilization. In the development of irrigation water supply systems, the provision of adequate drainage is a basic and often neglected operation. Most methods of irrigation do not permit absolute water control, i.e., maximum irrigation efficiency. Measured water application efficiencies often run as low as 25 percent and seldom exceed 80 percent.[1/] Maximum physical efficiency would be economically prohibitive because of the required inputs of capital and labor.

Drainage losses may be reduced through a combination of procedures. The most obvious is by construction of a drainage system of ditches, buried conduits, canals, and pumping plants. A method of lowering high water tables in many areas is the use of pumping plants that tap permeable aquifers. The value of the recovered water may cover the costs of pumping.[2/] In large areas of the San Joaquin Valley, groundwater is a major source of irrigation supply, and drainage problems can be handled within the irrigation districts by pursuing a policy of integrated management of ground and surface supplies. In other areas, such as the Imperial Valley, suitable aquifers either do not exist for pumping or the salinity of the groundwater precludes their use for irrigation.

1/ U. S. Department of Agriculture, Diagnosis and Improvement of Saline and Alkali Soils, Agriculture Handbook No. 60, 1954, p. 38.

2/ University of California, Water Resources Center, Drainage Problems in the San Joaquin Valley, by L. G. Wilson et al. (Los Angeles, 1958), p. 51.

Drainage losses are often reduced through the lining of canals and laterals. The benefits of lining conveyance systems include not only increased efficiency in operation and the prevention of losses during the peak seasonal need but also the alleviation of drainage and salinity conditions. Drainage losses may occur at some distance from the delivery points, and an investigation over a broad area may be required to discover actual or potential problems. It is stressed that there often is a significant interaction between the costs and benefits of the delivery and drainage conveyance systems.

Operation and Maintenance Costs.--Water conveyance systems are typically capital intensive. The proportion of total annual costs attributable to operation and maintenance is typically a relatively minor one. The operation and maintenance costs, for given capacity structures, are variable from site to site and from year to year at the same site.

Nevertheless, the design process for specific structures requires a thorough consideration of alternatives. One of the important decisions is between different combinations of capital investment and operation and maintenance expense with the objective of obtaining the lowest annual cost per unit of supply through the project life. A common example is the decision of whether or not to line a canal. The advantages of a lined canal are: increased capacity for a given cross section, decreased seepage losses and potential drainage problems, decreased maintenance costs, decreased excavation cost for a given capacity, and more direct routing of the canal. The advantages of an unlined canal are: substantially lower investment costs, particularly for small capacity canals, and a significantly larger infiltration capacity for recharging groundwater aquifers. The investment and operation costs are compared over the estimated economic life of the project to arrive at a decision. If the decision is to construct a lined canal, how thick should the lining be? Of what materials? Reinforced or unreinforced? Similar economic factors must be considered in most engineering design decisions.

Each structure site yields different data, and uniform design standards may not be economically desirable. Linsley has pointed out that design standards are often established by policy decisions or "good engineering practice." He is concerned that such standards shield the designer from imaginative design in special situations and result in excessive construction costs.[1]

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[1] R. K. Linsley, "Engineering and Economics in Project Planning," Economics and Public Policy in Water Resource Development, ed. Stephen C. Smith and Emery N. Castle (Ames: Iowa State University Press, 1964), p. 101.

A study of operation and maintenance costs done by the Bureau of Reclamation indicates that, during the period of 1939 to 1950, costs of operation and maintenance increased significantly faster than construction costs.[1] Approximately 80 percent of the total maintenance costs on a limited sample of lined canals was for labor; the remainder for materials. On unlined canals the proportion of labor was slightly higher. An important finding of the study was that the cost of maintenance per second-foot mile of capacity decreases sharply as the size of the canal increases.

Storage Structures

A central consideration of water supply planning is the time distribution of rates of flow. The rates of flow in naturally occurring surface supplies usually do not coincide with the time pattern of economic demands. The design problem is to move the patterns more closely in line. This may be accomplished by several different techniques including integrated management of groundwater basins, management of mountain snow packs, and water retarding structures, the most important of which are reservoirs. Reservoirs are constructed to move water from one time period to another. The wider the time divergence between rates of inflow and rates of demand, the larger the capacity required.

Each reservoir has a relatively unique cost-capacity relation because only a small portion, namely, the dam, is constructed. The cost per unit of storage is highly dependent on the natural features of the site. Much depends on the stream gradient, the length of dam required, and the suitability of the dam foundations. The economics of each potential reservoir site is uniquely determined by topographic, cultural, and geologic conditions. Thus, it is not to be expected that there exists any useful relationship between the size of the dam and the capacity of the reservoir, or the cost per unit of capacity and total capacity over all potential sites.

Studies of specific reservoir sites may produce very useful cost relationships. Figure 4 was developed from a 1949 study of the Oroville reservoir

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[1] U. S. Bureau of Reclamation, Maintenance Costs of Various Sizes and Types of Canals (Boulder City, Nevada, November, 1951).

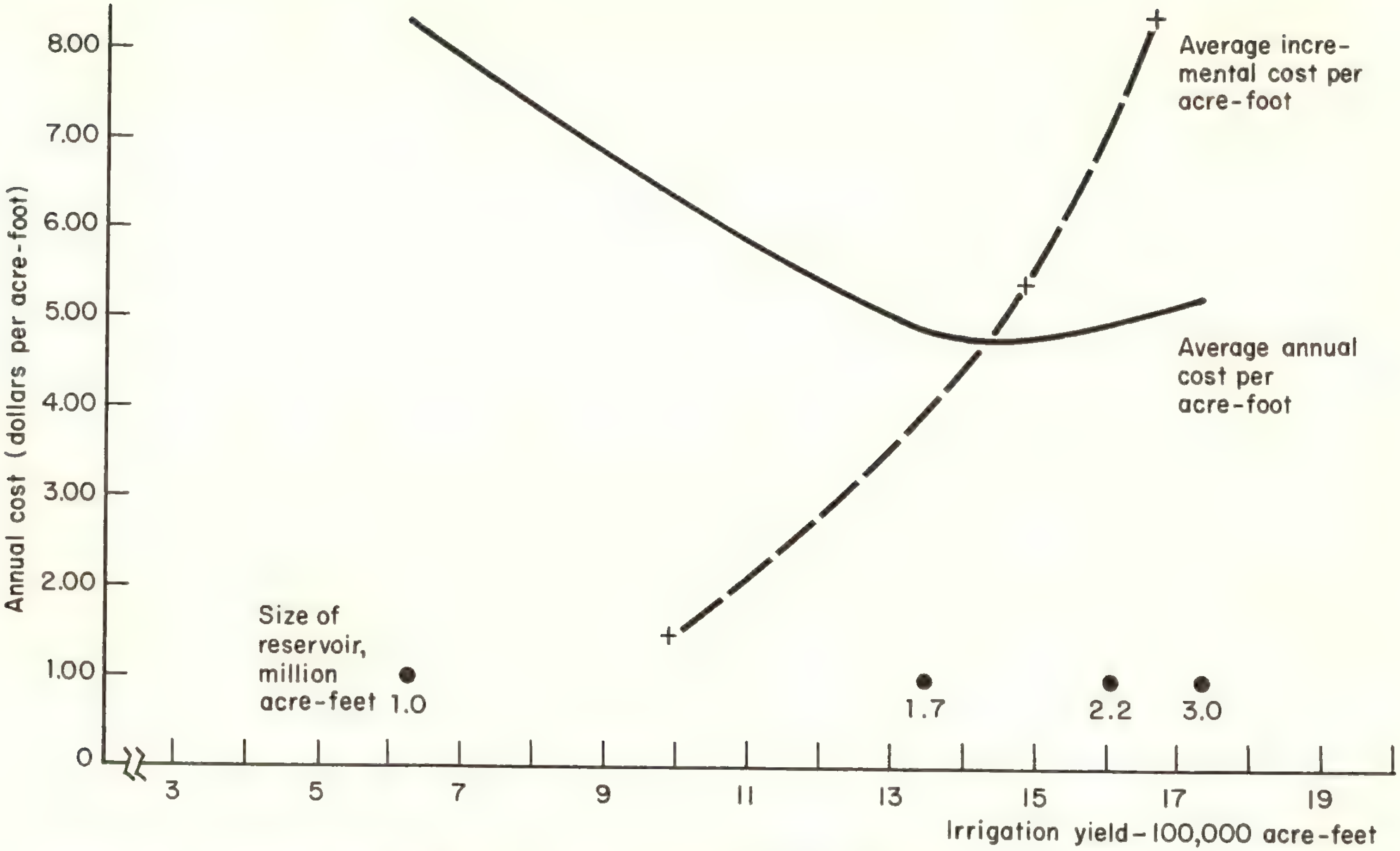

Figure 4. Cost-Yield Relationship for Irrigation Water: Oroville Reservoir

Source: Adopted from data in California Department of Public Works, Division of Water Resources, Report on Comparison of Oroville, Big Bend and Bidwell Bar Reservoir Sites for Development of Feather River (Sacramento, 1949) site on the Feather River.[1] This figure indicates that the average cost per acre-foot declines as reservoir capacity is increased to 1.7 million acre-feet, yielding approximately 1.35 million acre-feet of water during the irrigation season. If the reservoir capacity is increased to 3.0 million acre-feet yielding 1.75 million acre-feet, the average annual incremental cost of the yield obtained will be approximately $8.50 per acre-foot. These data are somewhat sparse but they serve to illustrate that a proper criterion for sizing a reservoir, with a water supply purpose, is the cost of the water yield obtained and not the cost per unit of storage capacity. However, we cannot conclude that the reservoir should be sized at 1.7 million acre-feet of capacity which produces the yield at least cost. The decision must be based on the demand relationships for the yield obtained and supply costs including conveyance. Studies based on comparison of alternative cost-output and demand schedules may result in a decision to size the reservoir at a larger or a smaller capacity.

The design of the storage reservoir is an integral part of the design of the entire supply system. The reservoirs at the point of surface flow are integrally related to regulatory or "terminal" reservoirs along the route of conveyance and to underground storage capacity where it is available, as well as to the conveyance links.

Economies of Size in Supply System Components

Most conveyance structures exhibit economies with increasing size; i.e., the cost per unit of capacity decreases with increasing capacity. This is a widely occurring phenomenon. Wiles has termed this relationship the "law of L-shaped costs" based on his wide-ranging empirical studies.[2] The economies of size in terms of capital cost are especially pronounced in the smaller sizes of canals and tunnels (Figure 5). Operation and maintenance costs also exhibit economies of size. The cost-capacity relationships of conveyance structures, as with reservoirs, are not meaningful until transformed

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[1] California Department of Public Works, Division of Water Resources, Report on Comparison of Oroville, Big Bend and Bidwell Bar Reservoir Sites for Development of Feather River (Sacramento, August, 1949).

[2] P. J. D. Wiles, Price, Cost and Output (2d ed.; Oxford, England: Basil Blackwell, 1961), p. 213.

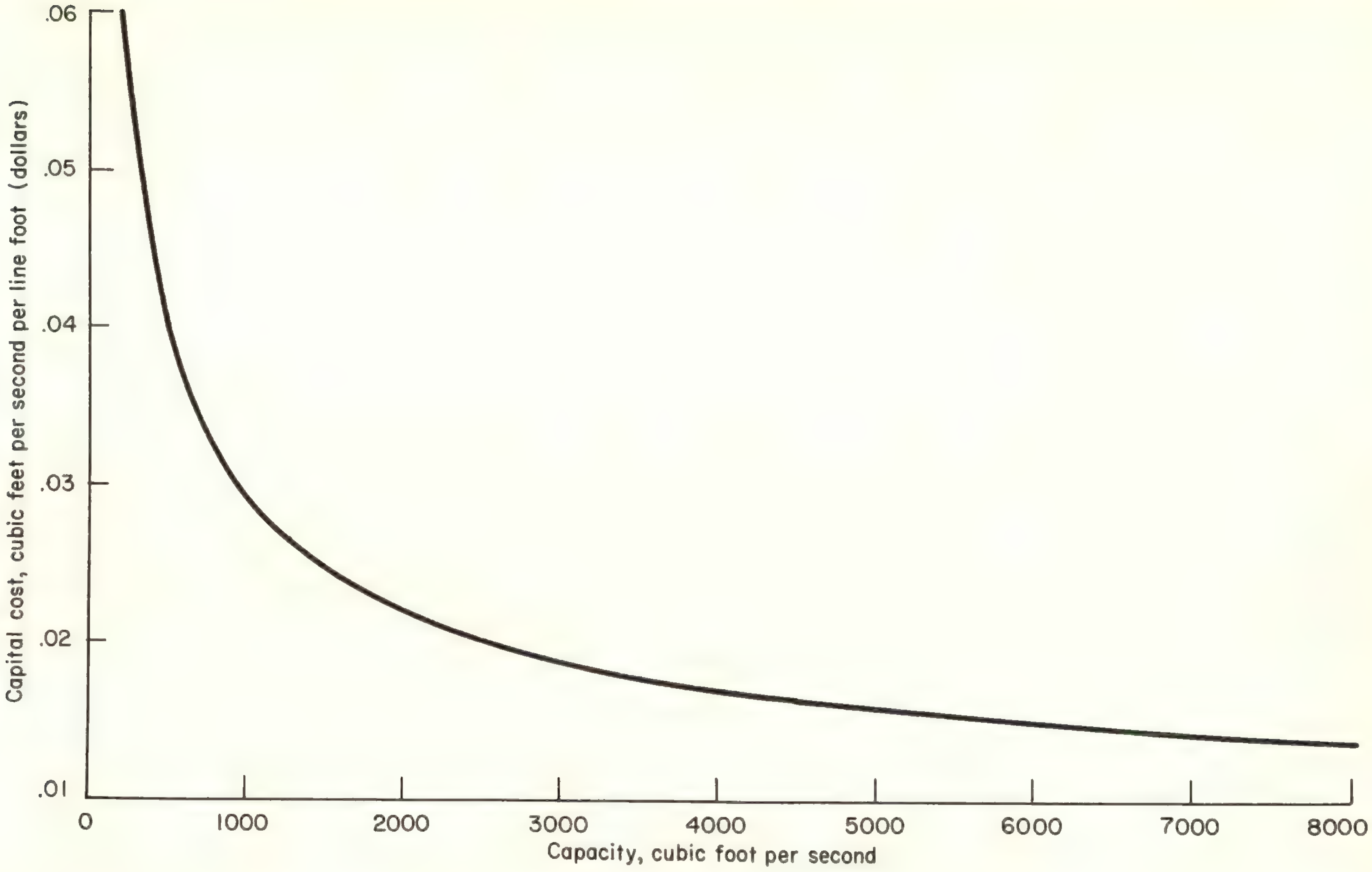

Figure 5. Canals: Capital Cost per Second Versus Capacity

Source: Adopted from unpublished data of the California Department of Water Resources, Sacramento into terms of costs per unit of water actually supplied. That is, large-sized structures are relatively more economic only if the additional capacity can be effectively utilized. In terms of public utility economics, the "load factor" must be maintained at a relatively high level in order to realize economies of size.[1]

Economies of size in the water supply system result from: (1) economies in construction of larger capacity conveyance structures; (2) economies of maintenance, operation, and administration; and (3) a reduction of variation in demand due to the compositing of individual demands.[2] Diseconomies of size are: (1) the increasing distance of conveyance required for large supplies and (2) the increasing costs of storage development.

Any source of water, except the ocean, is subject to eventual increasing costs per unit due to the physical limitations of supply. Increasing the size of service areas requires increasing distances of conveyance. Thus, while economies of size exist for individual structures within a supply system, the overall system is subject to eventual diseconomies of size due to natural supply limitations and increasing distances of conveyance.

Feasibility of Construction Staging

Water supply systems are investments that provide services over a long period of time. Principal and interest costs are a large proportion of annual costs. Therefore, capacity constructed in anticipation of future demand increases the current costs of supply. The design of the system development over time must consider the choice of lower annual capital costs through staged construction versus possible size economies in the construction of large capacity components in advance of demand.[3] Size economies vary with the physical components being considered.

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[1] J. M. Clark, Studies in the Economics of Overhead Costs (Chicago: The University of Chicago Press, 1957), Chap. XVI, "Public Utilities."

[2] *Ibid*.

[3] If excess capacity has been created in anticipation of future demand, there may be an opportunity to supply water at incremental costs for groundwater recharge or other low-value purposes for an interim period. See: Gary Taylor, "Pricing of Imported Water for Recharge in the San Joaquin Valley," Proceedings, 1963 Biennial Conference on Ground Water Recharge and Ground Water Basin Management, ed. Leonard Schiff (Fresno, California: U. S. Department of Agriculture, Ground Water Recharge Center, 1963).

Canals and Conduits.--There are very important economies of size in canal construction which in the past have discouraged serious attention to the staging of construction. However, it is evident in Figure 5 that with present construction methods the economies of size--that is, the cost per unit of capacity--are much less important for large canal capacities above 2,000 cubic feet per second (cfs). It is important to analyze staging possibilities for canals on large projects where the demand for water is expected to increase over the life of the project. Staging considerations are generally less important on small and medium-size irrigation projects that are supplemental to local supplies because full development will probably be rapidly attained.[1]

Economies of construction for increasing tunnel capacity are similar to those for canals. This relationship argues, in a similar fashion, for consideration of construction staging for large capacities. As was pointed out, cost estimation for tunnel construction is uncertain. For this reason, staging analysis cannot be precise. In planning for the southern California aqueduct, the Department of Water Resources concluded that staging of tunnel construction would not be advantageous.[2] This was questioned by a board of consulting engineers.[3] Ackerman and Löf have pointed out that rapid technological progress has been made in the machinery and techniques used in canal and tunnel construction.[4] Large-scale earth moving equipment and specialized equipment, such as canal trimming and tunneling machines, have been developed in recent years for use on large projects. This rapid technical advance lowers unit costs, increases the uncertainty of using current costs for staging analysis, and argues for deferred stages of construction.

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[1] U. S. Bureau of Reclamation experience has been that maximum irrigation demand is reached in approximately 5 years on presently irrigated lands and in approximately 10 years on undeveloped lands. Report on the Engineering, Economics, and Financing of the Feather River Project (San Francisco: Bechtel Corporation, December, 1955). Supplement by the Stanford Research Institute, p. 41.

[2] California Department of Water Resources, Investigations of Alternative Aqueducts to Serve Southern California, Bulletin No. 78 (Sacramento, January, 1959), p. 90.

[3] Ibid., p. 30. Report of the Board of Consultants: "Developments now unforeseen may occur in the field of construction, pumping, and power generation before the turn of the next century. We question the wisdom of building at the outset, in accordance with present anticipation of the total demands and technologies, for the remote future."

[4] E. Ackerman and G. Löf, Technology in American Water Development, Resources for the Future (Baltimore: Johns Hopkins Press, 1959), pp. 251-259.

Pipelines have fewer economies of size in construction than do canals and tunnels, and staging is accomplished by parallel lines of equal or unequal size. Siphons may be staged in a similar manner, even in canal systems initially constructed at full capacity.

Pumping Facilities.--It has been customary on large conveyance projects to construct pumping facilities in stages. The capital cost per unit of capacity is relatively uniform above 500 cfs, particularly at heads of less than 300 feet. Therefore, it is most efficient to add additional units of relatively small increments of capacity as demand increases over time.

Reservoirs.--The cost of reservoir storage is highly dependent on the quality of the natural sites available. Staging of construction may occasionally be economically accomplished on a particular site by staging the dam construction, or on a number of sites by adding reservoirs as required. The alternatives available in designing a particular system of reservoirs may be severely limited by the availability and quality of natural sites.

In summary, high quality in the design of water conveyance systems requires a thorough analysis of alternatives in construction over time. Simplifications of criteria that assume demand estimates for a particular time period are single valued may well lead to faulty decisions. Analysis should include the economic aspects of risk, uncertainty, and changing technology to the fullest practicable extent. Planning uncertainties are further discussed in the following section.

Formulation of Water Supply Systems

The planning group responsible for design of a water supply system can carry out its function of systematically evaluating alternatives in an effective manner only if the objectives of the development are or can be specified. Often the objectives are not clearly specified or they are subject to change during the period of planning which leads to inefficiencies in the planning process. In some cases when objectives are specified, they are overly narrow in concept and neglect important side effects.

The objective of planning was specified as the maximization of net benefits, over the economic life of the system, from the comprehensive viewpoint of the entire area affected by the development.1/ In this section, the applicability of this objective will be explored through an examination of the economic behavior and objective formulation process in public agencies and districts with considerations of the problems of planning under uncertainty.

The Public Agency as an Economic Unit

The concept of a water market as developed in the first section of this report is a useful construct in visualizing the planning approach to a water supply problem.2/ The planning agency is seen as evolving a market solution through the linking of alternative water sources and potential demands by means of a comprehensive water supply system that maximizes net benefits to the area affected.

The operation of a market in the traditional sense of separate groups of individual suppliers and demanders bargaining to establish prices of exchange is seldom observed in reality. Ciriacy-Wantrup has pointed out that actually the overwhelming proportion of water use in the United States is either self-supplied by water users or supplied by government or quasi-government organizations at administered prices.3/ In 1960 withdrawals of water in the United States were: 51 percent for self-supplied industrial use, 8 percent for municipal use, 1 percent for nonirrigation rural use, and 40 percent for irrigation. More than half the irrigation use is self-supplied with 90 percent

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1/ Supra, pp. 3-20.

2/ Ibid.

3/ S. V. Ciriacy-Wantrup, Projections of Water Requirements in the Economics of Water Policy, University of California, Giannini Foundation Paper No. 193 (Berkeley, 1960), p. 5.

of the remainder supplied by districts or mutual companies.[1] Thus, for some 90 percent of water supply, it is not possible to separate demanding and supplying groups, and most of the remainder is provided by municipalities whose economic behavior does not closely resemble the traditional "economic firm" in the marketplace.

In considering the planning for water supply by public and quasi-public organizations, the concept of a cooperative appears to be much more useful than that of the economic firm. The decision making in the firm is assumed to be independent of the behavior of other firms or consumers in the market except as it is expressed indirectly by prices for products or factors. In the cooperative form of organization, consumers (members) interact directly in the decision process establishing pricing and service policies.

An important incentive to create cooperative forms of organizations, such as government agencies, public districts, and mutual water companies, is to minimize the costs of service through the economies of large-sized organizations with prescribed powers and resources. The individual gains a supply of services at costs lower than those he would incur without the organization; and the uncertainty of future supply conditions, both in quantity and cost, is reduced.

The policies of the cooperative form of organization are formulated, through interaction of the membership, to optimize a number of objectives. Two principal objectives are the minimization of costs to the membership for agreed-upon levels of services over time and the equitable treatment of members in the operation of the organization. The pursuit of multiple objectives by the organization precludes the maximization of each as one objective acts to constrain another in given situations.

The term "optimization" is used here to mean the attainment of the highest level of all objectives of the organization as constrained by the attainment of a satisfactory level of each objective. This rather loose definition is thought to best describe the dynamic process of policy formulation which emerges from the interaction of the participating individuals within the cooperative form of organization and between the organization and outside groups and organizations.

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[1] K. A. MacKichan and J. C. Kammerer, *Estimated Water Use in the United States, 1960*, U. S. Department of the Interior, Geological Survey Circular 456, 1961, p. 32.

U. S. Bureau of the Census, *U. S. Census of Agriculture: 1959. Vol. III, Irrigation of Agricultural Lands*, 1962, Introduction, p. XXVII.

The pursuit of multiple objectives raises a serious problem in the design of a system because each of several objectives of the organization are not equally quantifiable. For example, while the objective of cost minimization for given levels of service is reasonably easy to handle, the data on attainment of satisfactory levels of equity may be generated by election of directors, by votes on bond issues, or by court decisions. Thus, some of the objectives of the organization are not directly measurable and are subject to considerable uncertainty.

Since the system designers are unable to incorporate all of the desired objectives within the maximizing framework on equal terms, some objectives must be introduced as quantified constraints. For example, the district distribution systems will be designed to serve every parcel of land; 50 percent excess capacity will be provided in all water mains for fire protection; or, no existing water rights will be impaired. These are design standards that are assumptions as to policies to be maintained in the future.

The use of alternative sets of constraining assumptions serves to generate estimates of quantifiable costs incurred in attaining different levels of nonquantifiable objectives. This information may then be used by the policymakers to re-evaluate the levels of each objective that the organization should maintain. The extent to which planning resources should be devoted to the evaluation of policy assumptions is a matter of judgment in each specific case--a problem of resource allocation in itself. However, there is no certainty that the highest level of optimization is attained unless policy assumptions are examined by some indirect method. Any analysis, of course, is incomplete without a clear and conspicuous presentation of the necessary policy assumptions on which it is based, in terms of quantified constraints.

Choice of Decision Rules in the Planning Process

Under the criterion of maximizing net benefits, the comprehensive planning model requires that a particular water supply system should be enlarged until the incremental cost of supply is equated with the incremental benefit or the alternative incremental supply costs at all points of potential demand over the economic life of the system. In practice, the size of a supply system usually depends on the level of comprehensiveness that is adopted in the planning phases. More specifically, the size of the supply system that is selected will depend on the size, resources, and objectives of the group that is developing the system. A small district, richly endowed with water resources--that is, water rights--may be too small to develop a system large enough to exploit the economies inherent in larger systems. The district controls water in excess of its needs as measured by the value of the water in alternative uses. Furthermore, its objectives will probably not include consideration of potential costs or benefits incident on others outside its boundaries as a result of drainage waters, water quality, or other external effects. The development of an undersized system will result in a misallocation of resources from a comprehensive viewpoint even though the size may be optimum from the district's viewpoint.

A state or regional agency would have the potential to design a maximizing system of larger size and to internalize effects external to the original district. The resulting situation would benefit all areas to the extent that size economies could be exploited by the larger system. However, it would benefit more than others those areas less favorably situated.

It does not necessarily follow that groups capable of adopting the more comprehensive viewpoint in terms of considering external effects and marginal equating techniques will, in fact, do so. Furthermore, there is little doubt that major planning agencies, considering similar resources but emphasizing different objectives--for example, development of irrigation versus supply of metropolitan areas--will, of consequence, arrive at different optimum systems. Thus, we can expect public agencies, in general, to act in the "public interest" of only the public they represent as reflected in the objectives they are pursuing. It is important to maintain a clear conceptual distinction between the maximizing solution of efficient resource allocation, as envisaged in the planning model, and the optimum of partial solution that may be obtained in practice because of the objective set of the agency or district developing the system.

In considering maximizing or optimizing criteria, it is important to make a clear distinction between benefits, revenues, and prices. Tangible irrigation benefits, for example, are usually determined through estimating the increased net value of agricultural production with the project. Revenues from water supplied may be obtained not only from water tolls but also from land taxes and assessments. The water supply system may be subsidized by other services from a multipurpose system; for example, hydropower, or by general tax revenues. The system conceptually could provide a surplus of revenues over costs. This case is seldom found in practice in the United States.

Under assumptions of marginal efficiency theory, the difference between benefits and water prices or tolls accrues to other factors of production, principally to land and labor incomes in irrigation developments. Increased returns to land may in turn be tapped by increased assessments and taxes as revenues to the supply system.

The marginal value in use may be expected to approach the prices charged. If water prices are low, irrigation efficiencies may be expected to be low with the risk of induced costs within and outside the service area from problems of drainage, salinity, and mosquito control. Incentives to increase efficiency in use may result from raising the water price and could lead to a more efficient allocation of water if alternative uses or external net costs do in fact exist. This is the role of price as a rationing device as opposed to its role as a revenue collector discussed above.1/

Pricing is an instrument to attain the multiple and often conflicting objectives of the district just as are taxing and other powers.2/ The pricing of water supply is conceptually separate from economic and financial feasibility analysis, but it is the direct concern of the planner because without assumptions as to pricing policy he is unable to make meaningful estimates of the quantities of water demanded or the project benefits.

Planning Over Time and Uncertainty

"Uncertainty enters into economic decisions whenever the consequences of a decision cannot be foretold with confidence, which is to say, almost

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1/ James C. Bonbright, "Two Partially Conflicting Standards of Reasonable Public Utility Rates," American Economic Review, Vol. XLVII, No. 2 (May, 1957), pp. 386-393. See also Troxel's comments on the chaos of present practices, ibid., pp. 403-405.

2/ Various pricing methods and their implications for water policy formulation have been reviewed and developed by Michael Brewer in Economics of Public Water Pricing, University of California, Giannini Foundation Research Report No. 244 (Berkeley, 1961), 33p.

always."[1] Unfortunately, we cannot wait for the future to provide us with the answers because the future is shaped by the actions of the present.

The traditional reaction to uncertainty is to adopt a policy of conservatism. This has been expressed in various ways in the criteria of project analysis. The estimated project life may be shortened. Estimated costs or physical design standards may be increased by a safety factor. Gross or net benefits may be arbitrarily reduced. Another approach is to incorporate a risk premium in the interest rate use to discount benefits and costs.[2]

There is reason to believe that more conservative approaches might well have resulted in the savings of resources invested in some overoptimistic water projects in the past. Nevertheless, economic design may err on either the side of conservatism or the side of optimism.

In this section, we shall be concerned with approaches that promise to improve the chances of the future success of a selected water supply system through the estimation of future conditions affecting the system and the incorporation of flexibility into the design.

Estimation of Future Conditions.--The success or failure of a water supply project depends in large measure on the relative demand and supply conditions in the future. Therefore, the estimation of these conditions is a key function of the planning process. The basing point is the current pattern of prices and contributing variables and their recent trends.

The projection of recent trends in demands and supplies may work reasonably well for short periods, but for planning horizons 50 to 100 years into the future the resulting estimates are likely to lack any great accuracy. The use of projections is common in government agency practice where projects are expected to have a long period of productivity and may, in fact, be required by law. They are, at best, informed estimates and are subject to abuses through ignorance or intent. Nevertheless, the construction and use of projections appear to be indispensable in the systematic evaluation of alternative projects and systems.

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[1] Robert Dorfman, "Basic Economic and Technological Concepts: A General Statement," in Arthur Maass *et al.*, *Design of Water Resource Systems: New Techniques for Relating Economic Objectives, Engineering Analysis, and Governmental Planning* (Cambridge: Harvard University Press, 1962), p. 129.

[2] Lutz and Lutz, *op. cit.*, pp. 179-192.

One area of weakness in the construction of projections has been in the concept of water "requirements."[1] In its simplest form, water requirements per capita or per acre are computed and multiplied by the estimated population or irrigated acreage to obtain the composite water requirement for a particular service area. Water requirements are not water demands, because not only water price but also other prices, income, preferences, demands for production, and technology are ignored or assumed to remain constant in their present relationships.

The second area of weakness is that projections are often taken much too seriously once they are made. That is, they are often treated as single-valued estimates even though they are at best the most probable values in a spectrum of possible outcomes.[2] Projected estimates should never be treated as "facts" because the facts can only be revealed by the events of the future. Projections are planning tools which are indispensable in the systematic planning of long-lived projects. As tools, they serve to provide guidelines which facilitate the orderly development of water resources. However, to expect that they can provide the answers from which the project of maximum economic benefit can be designed for an uncertain future period of time is unrealistic.[3]

If the future is uncertain and there may be a false sense of security in conservatism, how then are we to proceed to make decisions between alternative plans? Shackle has advanced the concept of bounded uncertainty: "In that theory the decision maker looks upon each act available to him as having a range of diverse possible outcomes, but their diversity is in every direction bounded by the inability of things to move, physically, psychically, institutionally, at more than some speed which we seek to name."[1] This concept visualizes a future of change without chaos which cannot be precisely forecast, but a range of possible outcomes can be estimated through knowledge and judgment as to the rates and direction of possible changes from the present situation. It follows that, as we consider outcomes further into the future, the range becomes wider and wider. That is, the more remote the events the less bounded is the uncertainty of their outcome.

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[1] Ciriacy-Wantrup, op. cit.

[2] Even the relatively straightforward analysis of hydrologic data is subject to considerable uncertainty. "It should be recognized that at the present, any studies of climatic records are dealing with relatively small samples from a largely unknown universe and that the results have unknown validity if extended into some future time period." Marion Clawson, "Sequence in Variation of Annual Precipitation in the Western United States," The Journal of Land and Public Utility Economics, Vol. XXIII, No. 3 (August, 1947), p. 271.

[3] For a recent analysis of the use of long-range projections in resources planning, see R. F. Daly, "Long-Run Economic Projections: A Review and Appraisal," Agricultural Economics Research, Vol. XV, No. 4 (October, 1963), pp. 113-121.

This concept is directly relevant to our consideration of projections. For example, one of the key variables in the demand for municipal water is population growth. If an estimate of population growth is projected for a particular area (e.g., Los Angeles for 1990), it will be based on a set of reasonable assumptions,and it is probable that it will also be wrong. How wrong? We do not know because there are no estimates on the probable range of outcomes. If additional projections are made, based on a realistic but conservative assumption set and a realistic but optimistic assumption set, we have an estimate of the most probable range of outcomes. This range can be further explored by use of a set of very pessimistic and very optimistic assumptions. This procedure is subjective and involves the full employment of the judgment and imagination of the planning group. It should not be confused with any procedure involving statistical probabilities as it is impossible to statistically test projections into future time periods.

The procedure illustrated above accomplishes two things. First, the estimate of the most probable outcome is made more meaningful by addition of an estimated range of possible outcomes. Second, the realism of the original assumptions can be compared with the optimistic and pessimistic assumption sets to see if there is an ordered array of assumptions from pessimistic to optimistic and if the "most probable" assumptions are still judged to be the most realistic within the spectrum. The most probable estimate with the accompanying estimated range of possible outcomes is less "precise" in that it does not yield the answer that is required for selecting the maximizing project design solution. It is, however, far more "accurate" in conveying the inherent uncertainties of future outcomes and makes possible a realistic appraisal of alternatives.

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[1] G. L. S. Shackle, Decision, Order and Time in Human Affairs (Cambridge, England: Cambridge University Press, 1961), p. 273.

When one considers the enormous number of variables and combinations which can affect the relative success of a given project, it becomes obvious that it is beyond the resources of the planning group to consider all of them with equal care. Once the initial estimates of variables have been made, the net benefits of a preliminary design can be determined. At this point, it is desirable to formulate a plan to revise these estimates through a technique sometimes called "sensitivity analysis."[1/] This simply means the determination of the effect of an error in an estimate on the net benefits of the project. For example, what effect would an error of 10 percent in estimating the acreage of cotton in 1975 have on the net benefits or time pattern of irrigation demand in the Madera Canal service area?

The Madera service area offers a striking example of the relative importance of errors in the estimation of demand variables. One of the key variables of total demand for water in metropolitan areas is population. However, the total population of Madera County in 1960 was only 40,500. At 150 gallons per person per day, the total annual demand for nonirrigation users was 6,750 acre-feet. In 1960, there were 138,000 acres under irrigation in the two districts with an average demand of approximately 3.2 acre-feet per acre, or a total annual demand of 442,000 acre-feet. Thus, in terms of total annual water demand, a 100 percent increase in population would be less important than a 2 percent increase in irrigated acreage. In this case, a simple extrapolation of recent past trends in population would probably suffice and the remaining planning resources could be devoted to the analysis of trends in irrigated acreage, irrigation efficiency, and other more critical variables.

Incorporation of Flexibility in Long-Range Plans.--Because the future environmental conditions affecting the supply system cannot be estimated with certainty, attention should be directed to designing a system which can successfully meet unforeseen conditions through increased flexibility. Flexibility is here defined as "capable of modification" and "adjustable to change." In comprehensive planning, flexibility characterizes a combination of physical structures, operating procedures, and institutional arrangements that can be

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[1/] For one discussion of sensitivity analysis, see Jack Hirshleifer, James C. DeHaven, and Jerome W. Milliman, Water Supply: Economics, Technology, and Policy (Chicago: The University of Chicago Press, 1960), p. 165. The technique is discussed under the designation of "Simulation" in Dorfman, op. cit., pp. 250-257.

adjusted to changing conditions over time. It is a rational attempt to meet the unavoidable inaccuracies in design data and estimates and the unforeseeable changes in the project environment over time.

Future environmental changes may influence the amount and location of demand or the amount and timing of supply from the developed source of the system. The amount and timing of water demands may be affected by changes in market demands for agricultural or manufactured production, changes in the technology of water use or water supply, or by changes in the population density or boundaries of the service area of the supply system. The amount and timing of water supplies may be affected by natural runoff or rainfall fluctuations, and changes in technology may affect the developed or alternative sources of supply.

The system should be designed to withstand "immoderate losses," that is, of a magnitude which would destroy the continuity of operation.[1] This implies a minimum standard of performance under the worst conditions. For example, domestic water and irrigation service for orchards must be provided during the worst possible drought period; the district must be protected against widespread tax and toll delinquencies; and physical structures must not suffer disastrous failures under extreme conditions (for example, dam breaks). These minimum standards are guaranteed at an additional expense, and their determinations are economic decisions.

Physical flexibility may be incorporated to meet shifts in the location and amounts of demand within the service area through provision of added capacity in the distribution system. Shifts in the timing of demand may be met through the use of regulatory reservoirs.

Economic flexibility is increased by lowering the proportion of fixed cost or capital investment per unit of service. In a static sense, the proportion of operation and maintenance (variable) costs is increased. In a dynamic sense, the capital investment may be added in successive increments to meet a buildup in water demand as required. The staging of physical structures[2] and a discussion of the decision to stage the construction of closed structures on the Madera Canal at 50 percent larger capacity is considered.[3]

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[1] Ciriacy-Wantrup, Resource Conservation: Economics and Policies (2d ed. rev.; Berkeley: Division of Agricultural Sciences, University of California, 1963), p. 88.

[2] *Supra*, pp. 21-32.

[3] *Infra*, pp. 49ff.

The incorporation of flexibility into a design is, in effect, a defense mechanism against adverse conditions. The use of sensitivity analysis is an approach which can highlight the critical variables in a system, and flexibilities can be incorporated at additional cost to prevent serious impacts on the relative success of the system from adverse occurrences in these variables. The objective is to insure some level of success of the system over time.

An important method of meeting uncertainty is to defer decision making. A supply system can be expected to be self-correcting in operation as experience accumulates. Operating procedures can be changed to increase efficiency, and minor structural changes can be made. In other words, there is a "learning period" during which opportunities to increase efficiency can be discovered. Additional information is generated which decreases uncertainty about certain design features.

An important example is the deferral of drainage system construction in irrigation development. The design of a drainage system in the absence of a drainage problem is far more uncertain than at the time when problems have begun to develop, following the accumulation of operational experience. Provision should be made during the initial planning for continued planning and financing to handle anticipated but still uncertain situations. The construction of the main canal, the distribution conduits, and drainage facilities are conceptually part of the same project system regardless of when or by whom they are constructed. If each is evaluated as an independent project, there is almost certain to be double counting of benefits.

Each new system is in a sense an experiment because each project environment is to some extent different from other projects. This is particularly true of the first project in an area, for example, irrigation projects in underdeveloped areas, where experience is not readily transferable from other areas. An important device for flexibility in new situations is the provision for research in the operating organization. This function is carried out by engineering staffs in large organizations. In irrigation developments, it may be provided by extension personnel and agricultural experiment stations. In some federal projects, the Bureau of Reclamation has carried out a research and education function through the use of demonstration farms.

There are many opportunities to improve the performance of the water supply system through research in using automatic equipment in the delivery system, infiltration of water to groundwater aquifers, drainage investigations, and so on. A largely unexploited area is the on-farm use of water (irrigation efficiency, weed control, leveling of fields, ditch layout, etc.), which could be improved in many cases to the benefit of both the irrigator and the district at reasonable costs.[1/] The use of extension and research assistance by the district to improve irrigation efficiency, for example, may be a cheaper alternative than the construction of drainage facilities. The conditions from district to district and from area to area offer varying possible returns from such activities. However, research and technical assistance should be considered in the evaluation of alternative flexibilities for incorporation in a water supply system.

The Role of Contracting

In this section, we shall consider the role of contracting in the formulation of water supply systems. This will be viewed not only in terms of the static concept of a formal agreement enforceable by law but as a dynamic process of decision making which can serve as a vital and useful role in the planning process. The contracting process will be considered in terms of its contributions to the reduction of uncertainty and the flexibility of the system under future conditions. The contracting process is here considered as the negotiations between organizations as, for example, between the Bureau of Reclamation and irrigation districts or the State of California and water districts, municipalities, or public utilities who in turn retail water to individuals or firms.

Reduction of Uncertainty.--The water supply contract is a formal agreement between two parties to provide specific quantities of water to particular organizations at definite times and delivery points and at specified prices. The contract commits each group, under pain of legal penalties, to carry out specified actions for a prescribed period into the future. Impending contract negotiations, therefore, are a strong incentive to contracting agencies to bring about a consensus within the group on the policies which will guide their representatives in formal negotiation.

[1/] A recent paper considers the advantages, from the engineer's viewpoint, of closer coordination of district and on-farm operations. John L. Merriam, "The Advantages of Flexibility in Irrigation Water Delivery," Presented at the 1964 Meeting of the California Irrigation Institute, January 27-28 (Fresno, 1964), 11p.

In the process of gaining consensus on policies, a considerable amount of information on variables of the water supply system is generated. Policy issues that have been in controversy or have lain dormant must be resolved in specific terms and conflicting objectives harmonized. The objective set of the organization is thus translated into specific goals to be striven for in formal negotiation. The range within which compromise is acceptable in reaching agreement, for example, on prices and quantities, is likely to be more refined than the estimates of the planning group prior to the attainment of consensus because the issues are put into sharper focus and the viewpoints of the water users are more accurately represented.

The negotiations of the contract serve to resolve issues resulting from different viewpoints of the participants. Final decisions are reached on design variables, such as the quantity, location, timing, and price of deliveries. These variables are then fixed and the uncertainty of both parties is thereby reduced. The wholesaling agency may proceed to refine the final design of the main supply and conveyance system. The retailing agency may refine its plans for deliveries to the water user. The water user, informed of the pricing and delivery policies of the district, may proceed with his plans for investment and production. One of the major contributions of contracting before the final design stage is the generation of information which puts the final plans on a more certain basis. The completion of contracting reduces uncertainty for all decision makers in the system and frees them to suboptimize at a higher level than if the state of uncertainty continued.

The completion, or substantial completion, of contracting for reimbursable project services, before the final design of the system, spreads the risk of failure to achieve financial repayment among all contracting parties. The contract financial obligations of the districts are secured by revenue collections and the land tax base. However, if the services are completely contracted, there is some residual risk borne by the delivery agency in that the contracts may not be politically enforceable during periods of physical or economic disaster, such as severe earthquake or economic depression.1/

1/ This point was made by Marion Clawson based on experience of the Bureau of Reclamation during the agricultural depressions of the 1920's and 1930's: Clawson, Organization and Administration, Part IV of Formulation and Economic Appraisal of Development Projects, Vol. I (New York: United Nations, 1951), p. 252.

Less severe circumstances might also force a renegotiation of contracts with reduced payments, longer repayment periods, etc.

From the viewpoint of the wholesaling agency, the soundest financial structure is provided by the complete negotiation of repayment contracts before construction is started. The opposite is true, of course, for the retailing districts. Once the main supply system is constructed, the balance of power shifts to them. However, as Clawson has pointed out for irrigation development, if the area to be developed must be colonized by irrigators, it is virtually impossible to negotiate repayment contracts several years in advance of water deliveries.1/ The development agency must assume the risk that satisfactory repayment contracts can be negotiated following construction of a supply system. The risk can be reduced to some extent by staging the development of blocks of irrigated land over time. Nevertheless, initial construction of a large reservoir and main canal system, in order to obtain the economies of size to secure the lowest supply costs when the source is completely developed, will entail a large degree of uncertainty in the negotiation of the initial contracts. Uncertainty will be reduced as additional blocks of irrigated lands are added. The development of water supplies in new areas is far more uncertain, both financially and economically, than in more developed areas where variables can be predicted with greater certainty.

Incorporating Flexibility.--The contract has been portrayed as a reducer of uncertainty through the formal specification of design variables over time. This rigidity, to the extent that it decreases uncertainty, contributes to the success of the system. However, to the extent that this rigidity reduces flexibility of the system to meet unforeseeable changes in the environment over time, it reduces the probable success to be attained. The incorporation of flexibility into the contract is, of course, a compromise between certainty and the ability to adjust to unforeseen circumstances.

The environment of the system can be expected to change in unforeseeable ways. The quantities of water demanded, the location and time patterns of demand, the uses of water, and characteristics of the districts, as well as relative prices and price levels, may be expected to change.

Water service contracts used on the Central Valley Project are provided under Section 9 of the 1939 Reclamation Project Act. Section 9(e) provides

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1/ *Ibid.*, p. 245.

for payment under a 40-year contract for irrigation water based on an appropriate share of the estimated operation, maintenance, and replacement costs, and such construction costs as are considered appropriate.[1] Section 9(c) provides for water supply for municipal and other uses.

The 9(e) and 9(c) contracts are not repayment contracts but utility-type contracts; that is, no amount or period of repayment is specified. Maximum delivery rates are specified at $10 per acre-foot for municipal use and $3.50 and $1.50 per acre-foot for Classes I and II from the Madera and Friant-Kern canals. Pricing flexibility is provided. The Bureau may set rates annually up to the maximum. Maximum quantities of Class I water are specified, and a period of increase up to 15 years is provided during which the district and the Bureau may determine the amount and schedule of deliveries. Following the 15-year period, the district is obligated to accept Class I water on the basis of deliveries requested previously.

The district may request changes in the quantities delivered between turnouts along that segment of canal serving the district. The district may further request permission to sell contracted water for use outside the district or to other districts, and the Bureau will deliver for a small charge if the capacity is available. The Chowchilla Water District has sold contracted water to districts along the Friant-Kern Canal.[2]

The Bureau of Reclamation is not liable for water shortages due to drought or unavoidable causes. The Bureau may withhold service in the event of payment defaults and the ownership of project facilities remains with the United States. All operation and maintenance costs on main storage and canal facilities are borne by the Bureau.

There is considerable flexibility provided under the laws and contracts pertinent to the Madera supply system. The districts may provide water for any beneficial use in meeting changing demands over time. The timing of deliveries is somewhat restricted, but the underground storage capacity permits operations to be flexible enough to receive the Class II water on a

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1/ U. S. Congress, House, Committee on Interior and Insular Affairs, Central Valley Project Documents: Part II. Operating Documents, 85th Cong., 1st Sess., 1957, House Doc. No. 246, p. 79.

2/ Personal communication with H. V. Eastman, Secretary-Manager, Chowchilla Water District.

when-available basis and to overcome the fixed nature of Class I deliveries as the need may arise.

It was not the objective of the Central Valley Project to require reimbursement of the full capital costs of main irrigation supply facilities by the contracting districts. However, the surplus revenues, available for repayment over the operation and maintenance costs of the Madera Canal, may be expected to be less than originally planned due to increasing operating costs. The operation and maintenance costs have more than doubled during the period 1953 to 1962, increasing from $56,000 to $137,000.[1]

The maximum contract price for water is fixed for a period of 50 years; and the inflation of overhead costs, which are in large measure labor costs,is likely to continue. It is probable that the excess available for capital repayment will be continually reduced on an average annual basis throughout the contract period. Thus, while the physical and legal flexibility is at a generally high level, the financial flexibility of the Madera supply system is flexible only in the direction of setting prices below the maximum contract price. It is inflexible in adjusting to rising costs of operation and maintenance.

In contrast to the Bureau of Reclamation, the State of California has adopted a policy of substantially complete reimbursement of Feather River Project costs from contracting districts.[2] The state has classified these costs into two major categories: those associated with supply development, the storage and other costs necessary to provide supplies at the Sacramento-San Joaquin Delta (Delta pool); and the transportation costs required to move the water from the Delta area to the contracting districts. The Delta rate is computed on an average cost basis. The transportation cost is computed on a proportional use of facilities formula, incorporating both the proportion of total annual deliveries and the proportional peaking capacity required.

Each of the two major cost categories is in turn segregated into the following annual breakdown: (1) capital cost component, (2) necessary minimum

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1/ Communication with the U. S. Bureau of Reclamation, Fresno Operations Office, Fresno, California.

2/ A statement of contracting principles is presented in California Department of Water Resources, The California State Water Project in 1963, Bulletin No. 132-63 (Sacramento, 1963), pp. 149-155.

maintenance and replacement component, and (3) a variable maintenance and operation component depending on the amount of water delivered. The amount of the capital cost component will be determined by construction costs which may be above or below planning estimates and will be fixed on an annual basis following construction. The minimum maintenance and replacement component is fixed with respect to annual deliveries but may be adjusted as required over time. The third component is directly dependent on variable delivery costs which include a sizable pumping power cost.

The state approach has provided flexibility with respect to cost changes over time and evaded financial errors resulting from reliance on planning cost estimates. The financial success of the project is reasonably well assured and the uncertainty of cost movements over time has been substantially assumed by the benefiting districts.

EMPIRICAL ANALYSIS: EXPERIENCE IN THE SAN JOAQUIN VALLEY WITH PARTICULAR REFERENCE TO THE MADERA CANAL

The Physical and Historical Setting

The Central Valley Basin of California is drained by the San Joaquin River from the south and the Sacramento River from the north. The floor of the basin is a gently sloping alluvial plain, 400 miles long and an average of 45 miles wide (see map). The Madera study area is located in Madera County on the east side of the San Joaquin Valley. It is bounded on the south and west by the San Joaquin River, on the east by the Sierra foothills, and on the north by the Chowchilla River. The area included is approximately 500,000 acres.

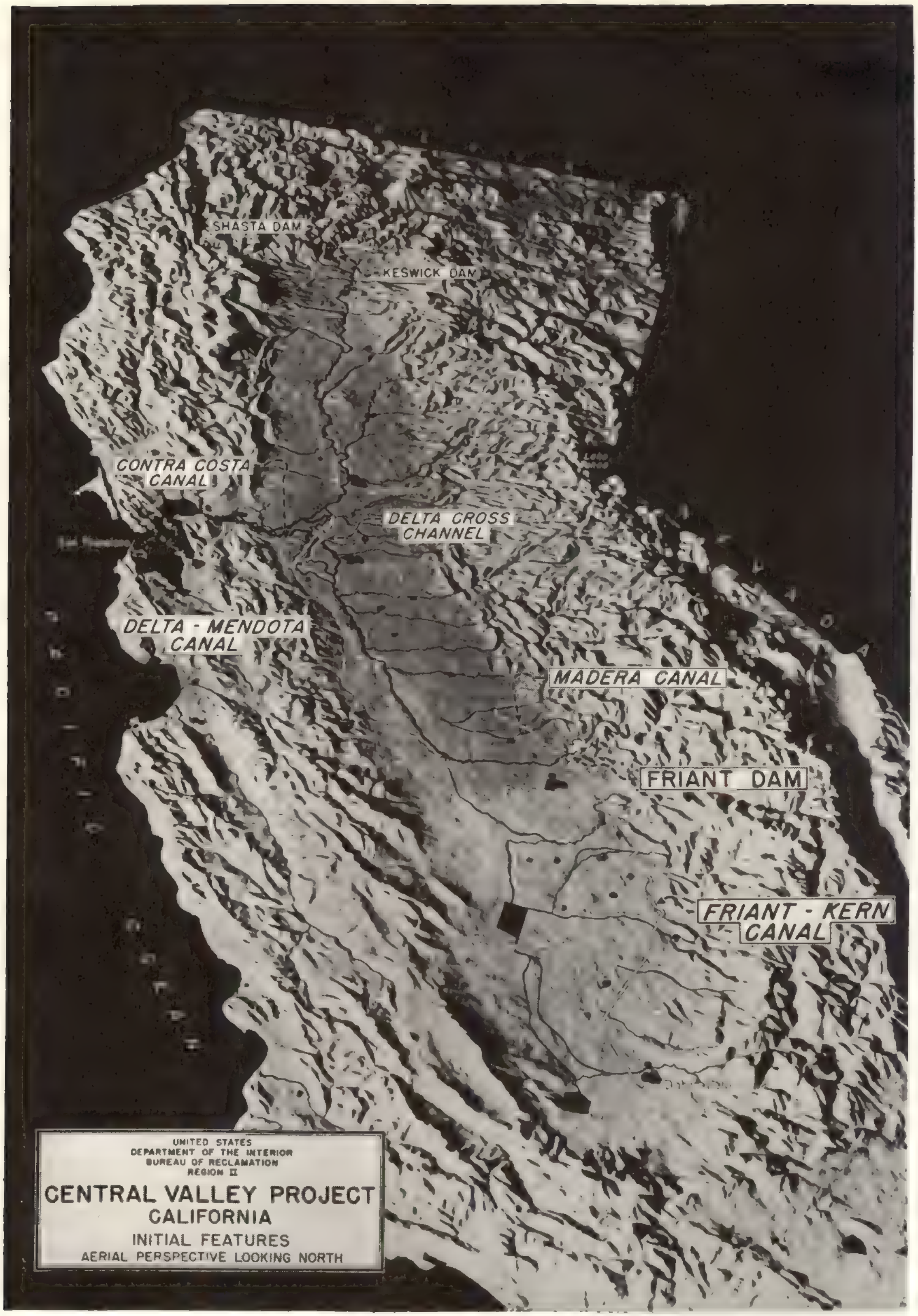
Early settlement in the Central Valley was discouraged by the dry, hot summers and the winter floods which inundated large expanses of the valley floor. Following the gold rush influx of population in 1850, cattle ranching and wheat production became highly profitable. The wheat boom was subsequently damped by sharp price declines, weed infestations, and declines in soil fertility.

The demise of wheat and cattle was followed by the initiation of irrigation where water supplies were available. Early irrigation developments were based on stream diversions by individual and informal groups of farmers. Later mutual and public utility companies were organized. The Wright Act of 1888 authorized public districts with taxing powers to develop irrigation. Public districts authorized by this and subsequent acts have loomed large in the water development of the Central Valley.

Early Planning by the Madera Irrigation District

The effort to develop water supplies for Madera County has had a long and, at times, turbulent history. In 1914 an irrigation bureau was formed and attention was directed toward development of conveyed supplies (from flood waters of the San Joaquin River) by storage at a site above Friant.[1/]

[1/] Frank Adams, Irrigation Districts in California: 1929, California Department of Public Works Bulletin No. 21 (Sacramento, 1929), pp. 199-203.


SHASTA DAM
KESWICK DAM
CONTRA COSTA CANAL
DELTA CROSS CHANNEL
DELTA - MENDOTA CANAL
MADERA CANAL
FRIANT DAM
FRIANT - KERN CANAL
PACIFIC OCEAN
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
REGION II
CENTRAL VALLEY PROJECT
CALIFORNIA
INITIAL FEATURES
AERIAL PERSPECTIVE LOOKING NORTH

In 1919 the irrigation bureau petitioned the County Board of Supervisors for information of an irrigation district which was approved by the voters the following year and contained an area of 350,000 acres.

During the period 1916 to 1922, the bureau and district filed applications for water rights on the San Joaquin, Fresno, and Chowchilla rivers. It was recognized that these applications were subject to claims of lower riparian owners and prior appropriations. A project for water storage at Friant would be impossible until conflicts with lower riparian owners were resolved.

In 1922 a truce was arranged between the Madera Irrigation District, Miller and Lux, Inc., and other riparian owners. The San Joaquin Water Storage District was formed to include the Madera Irrigation District and lands on both sides of the San Joaquin River. In 1928 a decision was made to dissolve the San Joaquin Water Storage District. The Madera Irrigation District was again faced with the original problem of acquiring a firm legal right to develop a water supply at Friant.

Water Planning for the San Joaquin Basin

In 1919, R. B. Marshall, Chief Geographer of the U. S. Geological Survey, offered a plan for comprehensive development of the Central Valley Basin. At this time, expansion of irrigation based on groundwater pumping had led to a substantial depression of groundwater levels in the upper San Joaquin Valley. Local supplies were inadequate to sustain this development over time. The conveyance of supplies from distant sources was beyond the financial capabilities of local areas. Investigations by the State Engineer's Office demonstrated that significant amounts of intensively developed irrigated land would be abandoned as declining water levels raised pumping costs. In 1921 the State Legislature authorized the State Engineer:[1]

> ". . . to determine a comprehensive plan for the accomplishment of the maximum conservation, control, storage, distribution and application of all the water of the state, and to estimate the cost of constructing dams, canals, reservoirs, or other works necessary in carrying out the plan."

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[1] As quoted in Sidney Twichell Harding, Water in California (Palo Alto: N-P Publications, 1960), p. 167.

The state planning in the 1920's was directed toward increasing water supplies for irrigation in the San Joaquin Valley where prevailing development, particularly along the east side of the Valley, was faced with declining groundwater levels. The initial objective was to provide sufficient additional supplies to prevent a decline in the current development. The longer range, often called the "ultimate," objective was to provide additional supplies enabling development of large additional areas of potentially productive agricultural lands.

The emphasis on agricultural water supply was not seen to be a narrow planning objective but rather to be the appropriate policy for overall economic development within the state.[1]

> "The agricultural lands, by reason of their flatter topography, their temperate climate, and their accessibility, are most suitable of all the state's lands for habitation. Except for the areas about the state's seaports, the urban communities of the future must largely spread over lands now classed as agricultural. Since cities of fairly mature growth use water about equal in amount to that required for irrigating crops on the same area, a plan that will provide an adequate allotment of water for all the agricultural lands, together with additional amounts for urban expansion about the state's seaports, will meet the future demands for water in the maximum development of the state's resources."

In many respects the state planning studies were unusually well done in terms of their scope, detail, and systematic analysis of alternative possible plans.[2] They represent a broad though rather sketchy picture of the prevailing amount, location, and proportion of crops irrigated; a general projection of future irrigation development; and the location and amount of potentially irrigable land.

The investigations of water supplies were organized as far as possible into areas delineating the important underlying groundwater basins; and studies were made of the pumping draft, the variation in levels of the groundwater, the natural inflow, and the per acre amounts of water required through importation to prevent a progressive lowering of water tables. The emphasis was on supply requirements rather than supply costs which may in part be rationalized by the water law institutions that permitted overlying owners to pump without restriction to the detriment of the group; i.e., there was no feasible control of pumping on private lands.

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[1] California Department of Public Works, Division of Engineering and Irrigation, Summary Report on the Water Resources of California and a Coordinated Plan for their Development: A Report to the Legislature of 1927, Bulletin No. 12, by Paul Bailey (Sacramento, 1927), p. 22.

[2] California Department of Public Works, Division of Water Resources, San Joaquin River Basin, Bulletin No. 29 (Sacramento, 1931).

The critical weakness of the state studies was a failure to analyze the value of the water supplies to be developed except in the vaguest of terms. Presumably the state intended to contract with the existing irrigation districts, but there is no evidence in the historical record that the prices or quantities of water which the districts could be expected to contract for were given serious evaluation.[1]

The state studies resulted in a comprehensive State Water Plan which was presented to the 1931 legislature. The Central Valley Project Act was passed and approved by referendum in 1933. A State Water Project Authority was created to administer the Act, and the sale of up to $170 million in revenue bonds was authorized. None of these bonds were ever sold, presumably because of the generally depressed economic conditions of the period. The state next turned to the federal government for financial assistance.

The Federal Central Valley Project

The first expression of federal interest in the overall Central Valley Project was the report to the President and the Governor of California by the Hoover-Young Commission in 1930. It recommended that the federal government contribute directly to the construction of units with navigation and flood-control benefits and possibly provide for low or interest-free financing for features providing other types of benefits.

The first direct allocation of funds for the Federal Central Valley Project was made by the President to the Bureau of Reclamation in September, 1935. This was an amount of $20 million that "shall be reimbursable in accordance with reclamation laws."[1] Additional grants were subsequently made, and the project was completely reauthorized as a Federal Reclamation Project in August, 1937.

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[1] These remarks are based on a more extensive analysis in Taylor, "The Economic Planning of Water Supply Systems with Particular Reference to Water Conveyance" (unpublished Ph.D. dissertation, Department of Agricultural Economics, University of California, Berkeley, 1964), pp. 60-88.

Objectives of the Central Valley Project in Historical Perspective

The pronounced objectives for water supply development in the Central Valley have undergone a series of changes and reversals over time which have affected the details of on-going planning. Both the Marshall proposal and the State Water Plan of 1931 stressed that additional water was required to develop land then unirrigated. Later, in statements made in behalf of federal financing, the emphasis shifted and the relief of lands going back to desert was stressed. The State Engineer stated in 1937 House hearings on the Interior Department appropriations bill:[2]

> "The canal capacities and the amount of water are all designed to serve only the land that is now under irrigation. It is not designed for new land. Of course, one cannot say that there will not be some acres here and there coming in, but the increase will be slight and slow, if any at all."

Some of the apparent conflict in objectives is explained by the concepts of initial development as authorized in the federal Central Valley Project versus the ultimate development of all irrigable land as proposed in the State Water Plan. The central objective of both stages of development, however, was the protection and increase of productive agricultural lands in the Central Valley.

We are concerned in this study with the development of water supplies for irrigation in Madera County. The Madera Canal was part of a much larger Central Valley Project which foresaw the eventual development of all irrigable lands in the Central Valley. The immediate problem was the provision of surface supplies to areas already developed from underground water supplies that were declining toward the limit of economic pumping.

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[1] Mary Montgomery and Marion Clawson, History of Legislation and Policy Formation of the Central Valley Project, U. S. Bureau of Agricultural Economics (Berkeley, March, 1946), p. 81.

[2] *Ibid.*, p. 78.

Planning the Madera Canal Under the Federal Central Valley Project

The Bureau of Reclamation cooperated actively with the California Water Project Authority in the initial phases of planning and construction. In August, 1936, the Water Project Authority submitted a report to the Bureau in support of its recommendations on sizing the Madera Canal.[1] In this report the state explicitly presented the policies and assumptions upon which the planning was based. The Authority anticipated that the Bureau would act as the planning and construction agency and the Authority would operate the constructed project and enter into contracts with the federal government to repay reimbursible construction costs without interest over a 40-year period.[2] These assumptions were later proved invalid, but the framework of the plan at this point was not affected.

The Authority proposed to limit its contracting to organized districts and agencies who would establish tolls and possibly assessments to pay for water and power from the project. Payments from districts were to be sufficient to meet all reimbursible financial costs and operation, maintenance, and depreciation costs. The project was to be considered a financial entity, and revenues from particular units might be used to pay costs of other units. Water supplies were to be paid for on a per unit basis at the main canal, and annual deliveries might be increased to the contract maximmm over a 10-year period.[3]

Delineating the Service Area

The objective of the plan was to establish delivery of a supplemental irrigation supply sufficient to enable full development of lands suitable for irrigation.[4] It was further noted that lands in Madera County not contained in the Madera Irrigation District were inferior in quality, and irrigation development could not be justified at this time or in the near future.[1] This assertion was substantially correct based on the earlier state San Joaquin investigations. However, in the interim period the district's boundaries had been changed and certain lands excluded. The original district area of 350,000 acres had been reduced to 173,000 acres by exclusion of lands, and the goal of the district in 1936 was for further exclusions to an area of 140,000 acres.

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[1] California Water Project Authority, Report on Capacity of Madera Canal (Sacramento, August, 1936).

[2] *Ibid.*, p. 6.

[3] *Ibid.*, pp. 7-10.

[4] *Ibid.*, p. 10.

Within the proposed area, 135,000 acres were classed as economically irrigable. Madera County was estimated to have 246,300 acres similarly classified. The proposed exclusion policy would reduce the proportion of potentially irrigable lands within the Madera Irrigation District from 84 to 55 percent of the County totals. It was the conclusion of the Authority, however, that the water supply should be based on a gross irrigated area of 130,000 acres or a net irrigated area of 104,000 acres.[2]

The above describes a problem in the delineation of a service area; namely, it is desirable to exclude unproductive lands to eliminate conveyance service costs, but it is desirable to include all productive lands to increase the payment base. The Madera situation presented the threat that if 45 percent of the lands classed as irrigable were excluded, they could be developed later by utilizing groundwater infiltrated from the conveyance system of the district with no cost other than pumping. The results of this decision will be discussed in the next section.

The total water supply required for full development was estimated by simply taking a figure, 2.5 acre-feet per acre, times net irrigable acreage, 104,000 acres, minus 100,000 acre-feet average annual inflow from Fresno and Chowchilla rivers, leaving a net requirement for conveyed supply of 160,000 acre-feet.[3] The Authority's report contained a preliminary plan for the district delivery system which included some unlined natural channels. It was estimated that these would result in irrecoverable losses of 10 percent. Thus, the gross conveyed supply was adjusted to 178,000 acre-feet per season on the average.[4]

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[1] Ibid., p. 11.

[2] Ibid., p. 10.

[3] Ibid., p. 30.

[4] Ibid., p. 32.

Determination of Conveyance Capacity

The maximum conveyance for the Madera Canal depended not only on the total annual deliveries but also on the time pattern of deliveries. Water conveyed to the district could be delivered in the surface conveyance system or infiltrated into the groundwater aquifers for later pumping, thus giving operational flexibility at the district level.

Operations studies of Friant Reservoir, which was to supply water to both Madera and Friant-Kern canals, resulted in the definition of two classes of water delivery. Class I water was intended as a surface supply to the irrigators and was to be made available on a firm delivery schedule, subject only to possible deficiencies in abnormally low runoff seasons. Class II water was all water in excess of Class I and was to be delivered on a when-available basis.

The Madera Canal was to be the first canal constructed from Friant Reservoir; and at the time of the sizing study, the district had a wide range of choice with respect to proportions of Classes I and II water. If the district chose to take 100 percent delivery of Class I water, the peak capacity requirement was 528 cfs because the district estimated its peak demand at 17 percent of annual delivery in June. If the choice was to have the entire delivery as Class II water, the largest monthly capacity requirement would occur in March at 893 cfs.[1] The more controlled flow, Class I, requires a larger reservoir capacity and a smaller conveyance capacity in a general way and vice versa. The various combinations of Classes I and II deliveries and their equivalent capacity requirements are presented in Table 1.

The reservoir studies at Friant indicated the total conveyance capacity most economic in combination with the reservoir capacity. There are striking economies of size in canals of the size being considered here. The capital cost of a canal of 1,000 cfs is on the order of 50 percent greater than one of 500 cfs.[2] The choice of all Class I water requiring the smallest capacity for the Madera Canal would necessitate an enlargement of the Friant-Kern Canal

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[1] *Ibid.*, p. 36.

[2] See Figure 5, p. 28.

TABLE 1

Delivery Patterns and Capacity Requirements
for Madera Canal, California

Average annual delivery		Peak delivery rate		Peak month
Class I	Class II	Per month	CFS capacity	
acre-feet		acre-feet		
0	178,000	54,893	893	March
29,667	148,333	48,235	784	March
59,333	118,667	41,535	675	March
89,000	89,000	37,868	636	June
118,667	59,333	35,705	600	June
148,333	29,667	33,558	564	June
178,000	0	31,395	528	June

to facilitate the delivery of a larger volume of Class II water. Thus, the choice of delivery pattern optimum from the point of view of the Madera District would not necessarily be optimum from the viewpoint of minimizing the supply costs of the larger system.

The negotiated choice of proportions of water in each class would depend in part upon the relative supply prices to the district which were not discussed in the above report. The 1931 State Report on the San Joaquin Basin proposed a price of $8.00 per acre-foot for primary water and an average price of $1.50 per acre-foot for secondary water.[1] In 1936 under interest-free federal financing, these prices were undoubtedly expected to be lower; but the choice in terms of price per unit of Classes I and II water was not made explicit.

The Authority anticipated that the district would elect to take at least one-third of the annual deliveries as Class I water. Thus, while the district maintained that it required 225,000 acre-feet annually, it was the conclusion of the Authority that a delivery capacity of 1,000 cfs was adequate even at the district's estimate if at least one-sixth of the supply was taken as Class I water.[2]

In May, 1939, the United States and Madera Irrigation District contracted to exchange the district ownership of Friant dam site and water rights on the San Joaquin River for a sum of $300,000. The contract called for construction of the Madera Canal at an initial capacity of 1,000 cfs diminishing in proportion to the area to be served. But all closed structures were to be 50 percent larger, thus providing for future enlargement if required. The district was given the option of contracting for an average annual supply from the Madera Canal up to 270,000 acre-feet, including up to 15 percent Class I water. The prices per acre-foot were not specified. The district was further permitted the option of excluding up to 40,000 acres and including up to 10,000 acres.[3]

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[1] California Department of Public Works, Division of Water Resources, San Joaquin River Basin, p. 425.

[2] California Water Project Authority, op. cit., p. 38.

[3] The contract is published in full in idem, Feasibility of State Ownership and Operation of the Central Valley Project of California (Sacramento, March, 1952), Appendix G, p. 239. This appendix also contains a copy of the contract of the United States and Miller and Lux, Inc., for purchase of riparian and "grasslands" water rights on the San Joaquin River below Friant for $2,450,000 in July, 1939 (p. 221).

Construction Progress on the Madera Canal and Pertinent Central Valley Project Features

Construction of the Madera Canal and Friant Dam began in 1940. Water deliveries to the district from completed sections of the canal were begun in mid-1944 and from the full length of the canal in 1945. Construction was started on the Friant-Kern Canal in 1945, and the first deliveries of water were made in 1950. It was 1951 before the first conveyance of water was initiated from the Shasta Reservoir in the Sacramento Valley through the Delta-Mendota Canal facilitating the exchange of Sacramento River water for San Joaquin water to supply water rights on the lower San Joaquin River, thus permitting the full operation of diversions from the Friant Reservoir.[1] This time lag in construction of other Central Valley Project features did not prove to be a restriction on the operations of the Madera Canal.

Contracting for Water Supply

Although water deliveries from the Madera Canal were begun in 1944, permanent contracts were not signed until 1951. This is attributable to two major issues: (1) the 160-acre limitation in the reclamation law and (2) internal dissension within the Madera Irrigation District which resulted in the secession of a group of landowners in the northern section of the district and the formation of the Chowchilla Water District.

The 160-acre limitation issue actually came into being with the first federal appropriation for the Central Valley Project which "shall be reimbursable in accordance with reclamation laws."[2] The controversy did not become really active until after 1940 when the construction program was well underway. It then was waged with such intensity and bitterness that

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1/ U. S. Bureau of Reclamation, History of the Central Valley Project (Sacramento, 1936-1961, annual issues).

2/ Montgomery and Clawson, op. cit., p. 81.

Section 5 of the original Reclamation Act of 1902 stated in part, "No right to the use of water for land in private ownership shall be sold for a tract exceeding 160 acres to any one landowner"; ibid., p. 132. This was interpreted under California community property laws to mean 320 acres under married ownership.

at this point it is almost impossible to discuss the limitation objectively because of the bias of the published sources.[1]

The Madera Irrigation District was deeply involved in this controversy because it was the first district to receive conveyed water under the federal Central Valley Project. Harry Barnes, Chief Engineer, expressed the district's dilemma in terms of technical considerations relevant to this study. The Friant Reservoir and Madera Canal were designed in part to provide water for storage underground. The storage underlies the entire district, and California law permits all landowners to pump freely from these aquifers. Since California law provides that all lands within a district shall be assessed at full cash value and provided a water supply proportional to that portion of the total assessments which the land bears, the land in excess of 160 or 320 acres not covered by "recordable contracts" would have to be excluded from the district.[2] Thus, the district could conceivably be fragmented and the assessment base reduced. The costs per unit of surface water distributed increased because of the lower density of turnouts, while the excess landowners benefited from the replenishment of groundwater without cost to themselves.[3]

After considerable controversy and litigation, the "160-acre limitation" was upheld by the U. S. Supreme Court in June, 1958. The Court in reviewing a group of four cases stated some of the equity arguments used by supporters of the contract limitations:

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[1] The interested reader is referred to all three of the following sources:

Montgomery and Clawson, op. cit.

Sheridan Downey, U. S. Senator, They Would Rule the Valley (San Francisco, 1947), 256p.

U. S. Congress, Senate, Subcommittee of the Committee on Irrigation and Reclamation, Hearings, on S. Res. 295, A Resolution to Investigate Problems Arising in Connection with the Construction and Administration of the Central Valley Reclamation Project in California, 78th Cong., 2d Sess., 1944, 503p.

[2] Recordable contracts are agreements by landowners to sell excess land at prices reflecting land values prior to project water deliveries within a period of 10 years. During the interim period, excess lands can be provided with project water.

[3] Harry Barnes' statement at hearing quoted in Downey, op. cit., pp. 133-138.

> "As to the claim of discrimination in the 160-acre limitation, we believe that it overlooks the purpose for which the project was designed. The project was designed to benefit people, not land. It is a reasonable classification to limit the amount of project water available to each individual in order that benefits may be distributed in accordance with the greatest good to the greatest number of individuals."[1]

Noting that the cost of the project will never be recovered in full, the Court maintained the government's right "to regulate that which it subsidizes."[2]

In practice, the areas of the districts and their operational effectiveness were maintained. In fact, the question of groundwater replenishment under "excess lands" was resolved by the contracts which freed the districts from responsibility for such replenishment as a result of normal operations to replenish aquifers underlying nonexcess lands.[3]

Many of the excess-land holders were persuaded to sign recordable contracts because the efforts of the Bureau and district people were patient and persistent and because it was in the interest of the excess-land owners to receive the surface deliveries for the interim period of the contracts.[4]

The second major factor in the delay of permanent contracts was internal dissension within the Madera Irrigation District. In 1947, 30 landowners organized the Chowchilla Irrigation Committee and began a long series of negotiations which eventually resulted in the exclusion of 46,000 acres from the Madera District which was combined with 19,800 acres formerly outside the Madera District to form the Chowchilla Water District.[5] The new district received a portion of the water delivery guarantee granted to the Madera District by the United States in 1939 and a portion of the cash assets. The formation of the new district was approved by a vote of 12 to 1.

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[1] "United States Supreme Court Decision," Western Water News, Vol. 10, No. 7 (July, 1958), p. 6. The U. S. Supreme Court decision in the Ivanhoe Irrigation District case and others was reprinted in full in *ibid*., pp. 3-6.

[2] *Ibid*., p. 6.

[3] Section 34, Contract Between the United States and the Ivanhoe Irrigation District Providing for Water Service and for the Construction of a Distribution System, dated September 23, 1949. Reprinted in California Water Project Authority, Feasibility of State Ownership . . ., Appendix G, p. 253.

[4] Personal communications with Bureau and district personnel. There also appeared to be a belief that the contracts would ultimately not be enforced. The Bureau of Reclamation is currently taking steps to effect enforcement.

[5] U. S. Bureau of Reclamation, Factual Report: Chowchilla Water District, Central Valley Project, California (Fresno, March, 1950), p. 3.

The dissident group felt that the groundwater levels were declining rapidly and that the directors of the Madera District were not moving rapidly enough in negotiating a permanent contract for delivery of water. There was further a sharp difference of opinion on the planning criteria for the district conveyance system. The Chowchilla Committee felt that a complete system was unnecessary in their area and that considerable savings could be accomplished by conveying waters in the natural distributaries of the Chowchilla River augmented by short laterals from these channels.[1]

Following the completion of negotiations to establish the new district in late 1949, both districts resumed negotiations with the Bureau of Reclamation. The Chowchilla Water District completed a contract for water service in July, 1950. The Madera District completed a contract for water service and a distribution system loan in March, 1951.[2]

The delay in contracting was costly in lost revenues as well as in ill will and wasted planning effort. Table 2 presents data on the deliveries and water revenues for the Madera Canal for the years 1944-1951. Under the assumptions presented, lost revenues from actual deliveries were approximately $380,000. Following the completion of contracting, water deliveries were substantially increased. This indicates that some potentials for additional deliveries in the period 1944-1951 were probably foregone. Furthermore, irrigators incurred additional pumping costs that probably would not have been otherwise required. In view of these factors, it is probably a conservative estimate that the losses sustained by a seven-year delay in contracting on the Madera Canal were more than 15 percent of the capital cost of $3.4 million. The failure to obtain contracts for water deliveries resulted in losses in excess of probable errors that might have occurred in the engineering or economic planning of the canal.

1/ Personal communications, with H. V. Eastman, Secretary-Manager, Chowchilla Water District, and Fredrick G. Bandy, Secretary-Manager, Madera Irrigation District.

2/ California Water Project Authority, Feasibility of State Ownership . . ., p. 70.

TABLE 2

Interim Deliveries and Revenues, Madera Canal, California

Fiscal year	Deliveries	Revenues	Average price
	acre-feet	dollars	dollars per acre-foot
1944	46,525	12,800	0.275
1945	133,121	45,000	0.338
1946	106,880	55,459	0.519
1947	74,781	49,457	0.661
1948	20,082	30,123	1.50
1949	92,803	139,242	1.50
1950	140,898	211,382	1.50
1951	121,765	182,648	1.50
July and December, 1951	115,045	172,567	1.50
Total	851,900	898,678	

Source: California Water Project Authority, Feasibility of State Ownership and Operation of the Central Valley Project of California (Sacramento, March, 1952), Tables 15 and 16, p. 78.

Assuming conservatively that all deliveries were Class II:

Potential revenues from precontracting (851,900 acre-feet at $1.50 per acre-foot)	$1,277,850
Actual revenues	898,678
Loss of revenues to the federal government due to the failure to precontract	$ 379,172
Estimated construction cost of the Madera Canal	$3,416,000

(U. S. Congress, House, Committee on Interior and Insular Affairs, Central Valley Project Documents: Part II. Operating Documents, 85th Cong., 1st Sess., 1957, House Doc. No. 246, p. 60.)

Planning of the District Conveyance Systems

Under terms of California law, irrigation and water districts are empowered to provide and operate systems of water supply and drainage. The objectives of the districts in their operation are twofold. They are concerned with efficiency in the provision of services at low unit cost and with equity in the provision of roughly equivalent services to all district members. The irrigation districts, for example, are required by law to furnish water service in proportion to their assessments on unimproved real estate.

The Madera and Chowchilla Districts have approached the problem of designing conveyance systems in radically different ways. The Madera District has planned a complete surface system of canals and laterals to serve all lands within the district. The Chowchilla District has taken advantage of a natural system of distributaries from the Chowchilla River which serves as both conveyance channels and infiltration grounds for recharging the underground aquifers. The utilization of these channels, which have laterals constructed from them for limited surface distribution, has resulted in a much lower capital investment than the Madera system. This was clearly not an either/or choice, however, because the Madera District has had to rely primarily on surface spreading of waters on fallow lands because of the lack of suitable natural infiltration capacity.

In planning the Madera Canal, it was necessary to plan a distribution system on a tentative basis in order to locate the delivery points from the canal. The state designed a preliminary plan to provide surface delivery to the entire proposed district area utilizing natural channels wherever possible and following low ridge lines in a number of instances. This plan was estimated to cost $1.5 million for delivery to each 160-acre tract and $2 million for delivery to each 40-acre tract.1/

The separation and formation of the Chowchilla District led to a revision of the delivery system plan. The Madera Canal had been constructed at this time, but the location of turnouts fitted the new conditions well. The 1949 plan called for 459 miles of open, unlined canals located along

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1/ California Water Project Authority, Report on Capacity . . ., pp. 30-32.

section and half-section lines with a minimum capacity of 15 cfs. The old plan of following ridge lines was revised to prevent the bisection of fields and thereby lower rights-of-way costs.

In 1960 the estimated total capital value of the Madera District's distribution system was $8,900,706.[1] In February, 1959, district voters approved a supplemental contract between the United States and the district for construction of additional distribution system facilities with total expenditure limited to $5,177,000.[2] Thus, the completed cost of the Madera distribution system is estimated at approximately $14 million.

Following formation of the Chowchilla Water District, some 90 miles of canals were planned to distribute water to all parts of the district but not to every parcel of land.[3] Some of these laterals were built by legally established improvement districts and others by informal groups of farmers but none by the district. These laterals were locally financed with the exception of four improvement district bond issues, and most of the rights-of-way were donated. The investment in laterals was roughly $1 million. The unit cost was estimated by the district to be approximately one-fourth the cost per unit of similar developments by other districts in the San Joaquin Valley.[4]

Experience proved that the resulting system was not effective in years of high or low surface supplies. In 1960 the district negotiated a federal interest-free loan of $2,650,000 for construction of additional distribution facilities and a small reservoir.[5] A supplemental loan of $600,000 was added in 1962. In addition, the district borrowed $300,000 through general obligation bonds to purchase rights-of-way for the new system additions.

A substantial portion of the federal loan is being subloaned to improvement districts benefited by new construction. These loans are prorated to landowners on an acreage basis and are repayable to the district through increased land assessments. Some 17 improvement districts have been organized, and the costs on a prorated basis vary from $9 to $95 per acre.[1] In addition to lateral construction, the district is building a small reservoir above the district distribution system to gain more timely control of delivery rates. The lag time with control at Friant Dam is two days. This is expected to be cut to six hours through operation of the reservoir.

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[1] Madera Irrigation District, Audit Report for the Year Ended December 31, 1960 (San Francisco: Richard Hanlin and Co., 1961), p. 5.

[2] Ibid., p. 11.

[3] Chowchilla Water District, Prospectus in Connection with an Offering of $100,000 of General Obligation Bonds, 1960, p. 6.

[4] Ibid., p. 6.

[5] Ibid., p. 3.

It is anticipated that approximately 60 percent of the Chowchilla District will be served by surface laterals delivering approximately 40 percent of total supply with the remaining 60 percent pumped from the groundwater aquifers.[2]

In summary, the two districts in the Madera Canal service area have adopted different policies with respect to development of district conveyance systems. The total investment in these systems has been substantial. The Madera District plans a total investment of approximately $14 million. The Chowchilla District, with its structure of improvement districts, will have an investment of over $4.5 million. The cost of the Madera Canal was approximately $3 million at 1944 prices or approximately $4.5 million on the basis of 1960 prices.[3] Thus, the real investment in conveyance systems in the Madera service area is roughly four times the investment in the Madera Canal.

Operation of the Madera Supply System

The first deliveries of water were made from the Madera Canal in 1944. During the 20-year period which has elapsed, sufficient experience has been gained to generally assess the planning and operation of the project.

Water Deliveries to the Madera Service Area

Data on water deliveries from the canal are illustrated in Figure 6. The outstanding fact is that the average annual contract entitlements of water were not delivered until 1965. Early deliveries were erratic until permanent contracts were completed in 1951. Following completion of negotiations,

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[1] Personal communication with H. V. Eastman, Secretary-Manager, Chowchilla Water District.

[2] Ibid.

[3] Estimated from the canal cost index in U. S. Bureau of Reclamation, Construction Cost Trends (Denver, Colorado; quarterly issues).

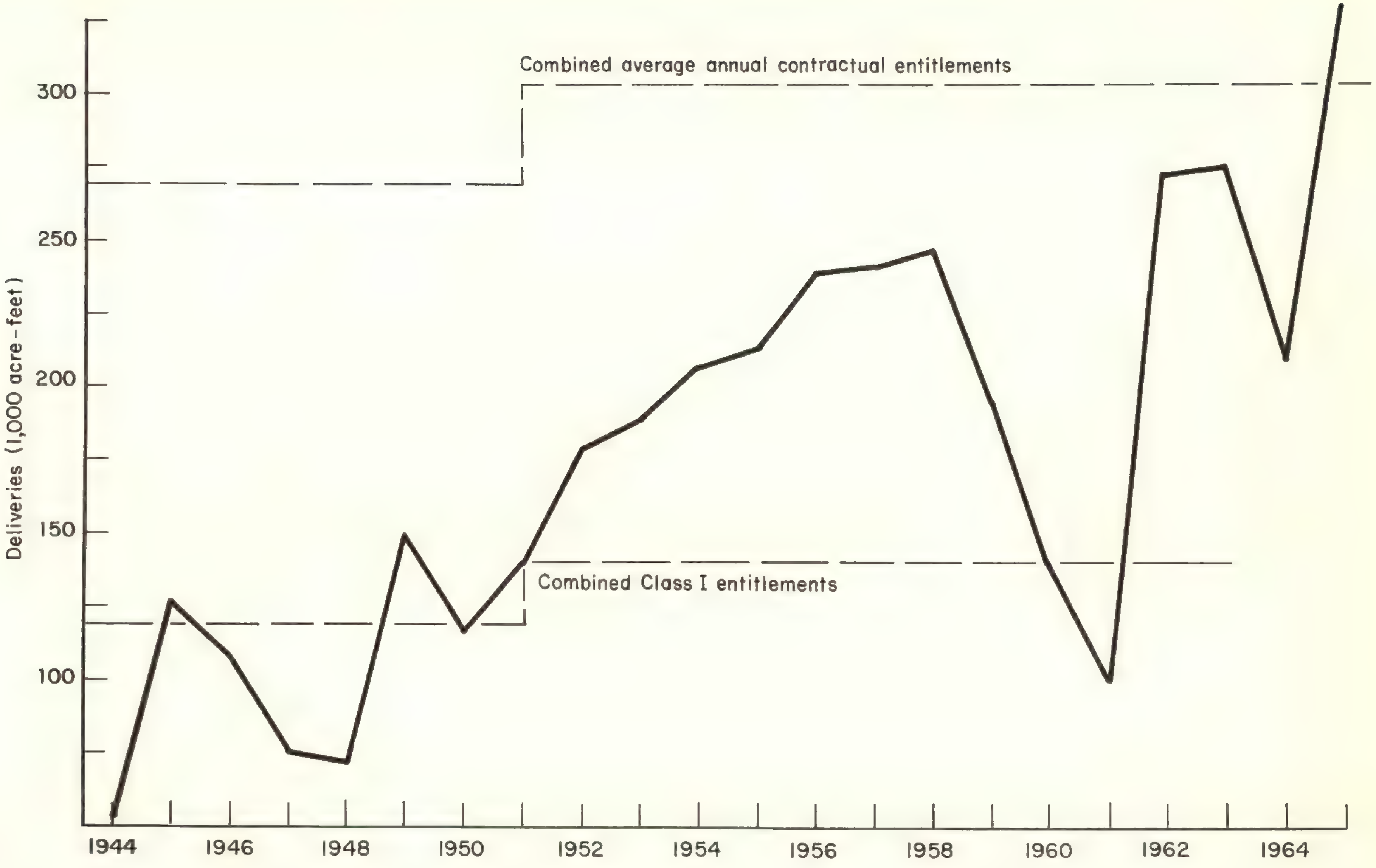

Figure 6. Deliveries from Madera Canal, 1944-1965

Source: U.S. Bureau of Reclamation, Fresno Operations Office the deliveries rose steadily until the unusually dry period of 1959-1961 cut back the available water at Friant Reservoir.

One of the reasons given earlier for the formation of the Chowchilla Water District was the strong concern about declining groundwater levels. The Chowchilla District, although a smaller area, received deliveries in excess of the Madera District from the time of formation until the middle 1950's. The effect of this is clearly demonstrated in Figure 7 by the general stability of groundwater levels under the Chowchilla District during the 1950-1958 period. A similar stability was evidenced by the Madera groundwater levels during 1954-1958 following increased deliveries. The relationship is only general because the deliveries available at Friant are positively correlated with the natural inflow to the groundwater aquifers and the effective rainfall on the districts. The groundwater levels under both districts plunged during the unusually dry period 1959-1961. The drought restricted the deliveries available from Friant Reservoir below Class I entitlements in 1961, reduced natural inflow to the underground, and increased pumping drafts.

Irrigation Development in the Madera Service Area and Madera County

In 1939, when the United States and the Madera Irrigation District agreed on the initial capacity of the Madera Canal and total annual delivery, the Madera Irrigation District contained approximately 95 percent of the irrigated crop acreage in Madera County. It was presumed to be a reasonable assumption that the district was the Madera service area and that irrigation development outside the district boundaries would not significantly impair the effectiveness of the district's management of the groundwater aquifers underlying the service area.

From 1939 to 1948, the irrigated acreage in the Madera Irrigation District rose 30 percent, and the formation of the Chowchilla Water District the following year brought into the Madera service area approximately 20,000 acres previously irrigated. In the past 10 years, the total irrigated acreage within the two-district service area has fluctuated around 136,000 acres (Figure 8). Thus, during the 25-year period, 1939-1964, irrigated acreage within the district areas served increased 70 percent.

It is doubtful that deliveries from the Madera Canal actually induced the rapid expansion because during the same period irrigation in Madera County

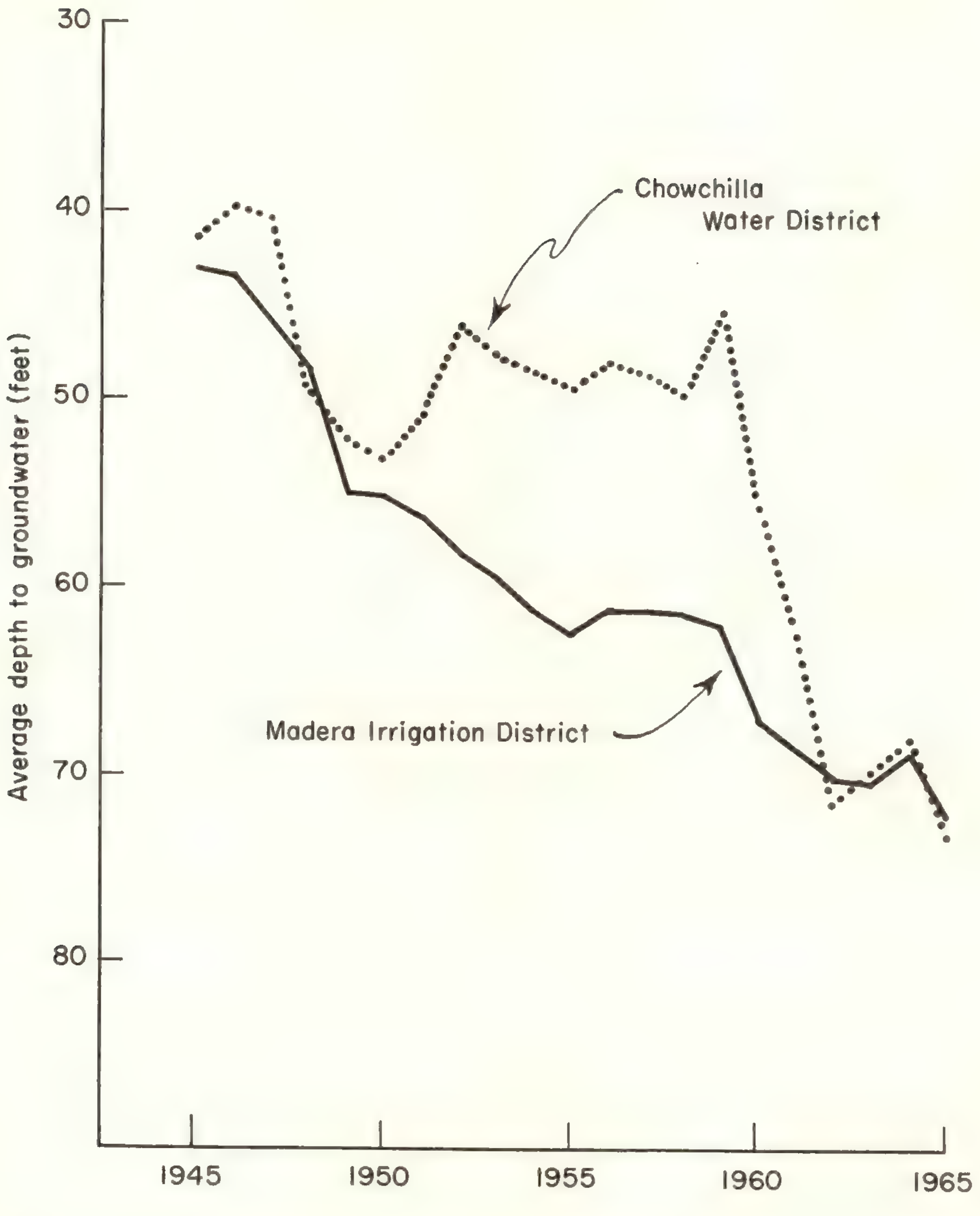

Figure 7. Depth to Groundwater, Spring, 1945 - 1965

Source: U.S. Bureau of Reclamation, Fresno Operations Office

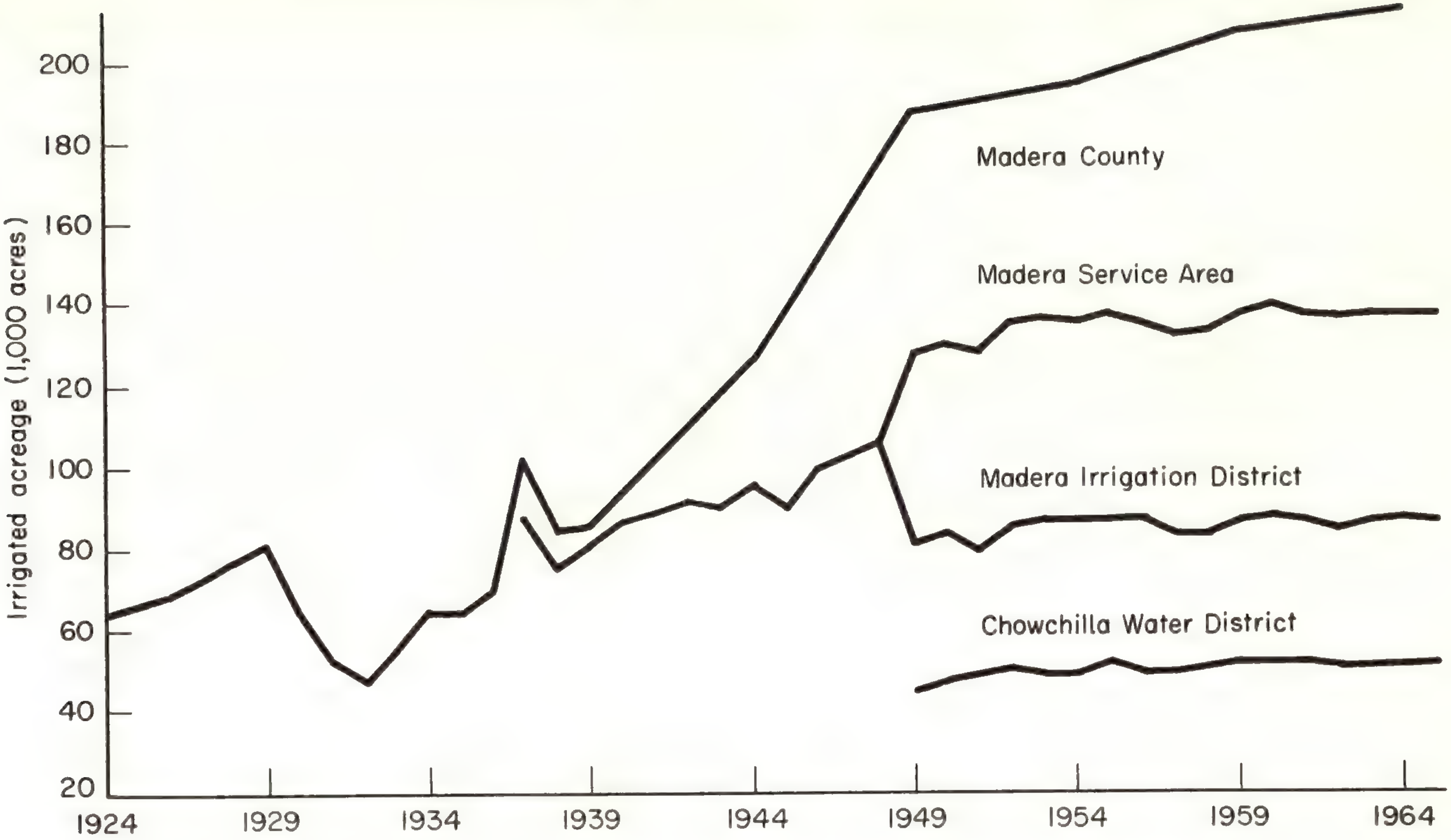

Figure 8. Acreage Irrigated: Madera County and Madera Service Area, 1924 - 1965

Sources:

1924 - 1929: For Madera County irrigated acreage, California Department of Public Works, Division of Water Resources, San Joaquin River Basin, Bulletin No. 29 (Sacramento, 1931)

1930 - 1938: James F. Sorenson, "A Study of the Demand and Available Water Supply for Irrigation in the Madera Irrigation District" (unpublished Master's thesis, Department of Civil Engineering, University of California, Berkeley, 1941), Appendix Table 15

1939 - 1964: U.S. Bureau of the Census, Census of Agriculture, 1940, 1945, 1950, 1954, 1959 and 1964 (preliminary)

1924 - 1964: U.S. Bureau of Reclamation, Fresno, California outside the district areas increased from approximately 5,000 acres to 76,000 acres. That is, the proportion of Madera County irrigated acreage within the two-district service area declined from 95 percent to 64 percent. The failure of the original assumptions as to the relevant service area for the Madera Canal is one of the most serious failures of the original plan. Most of the outside acreage is supported by pumping from underground aquifers that are being replenished by deliveries from the Madera Canal to the two districts. The problem, of course, is that the outside irrigators are nonparticipating beneficiaries.

Cropping Patterns in the Madera Service Area

The proportions of irrigated areas devoted to different crops are important because this information is required to estimate benefits or net returns from irrigation by means of residual budgeting or other techniques; and, from the physical aspect, this information is required to estimate the amount and timing of irrigation water demands.

Table 3 presents data on the proportion of various crops irrigated in the Madera service area. Cotton has been the leading crop for over 40 years. Alfalfa and vineyard acreages are similar in importance and with cotton have accounted for roughly two-thirds of the irrigation over time.

In 1950, the Bureau of Reclamation made forecasts of the proportion of various crops irrigated under "ultimate" or full development conditions. These estimates resulted from a study of the productive resources and location of the area in relation to anticipated market conditions. These are presented in Table 3. After a decade, the estimated proportions of irrigated crops under full development are as close to the present proportions as might be reasonably expected. The acreage of the leading crop, cotton, is under political control, and trends in acreage are not readily predictable over time. It is presently relatively more profitable in the area than was foreseen but not necessarily at the world price. The Bureau estimates were optimistic with respect to irrigated pasture and pessimistic with respect to vineyard acreage. It is doubtful that the estimates could have been significantly improved. The Bureau personnel worked with Extension and University personnel knowledgable of the area and market potentials. There is no evidence that the Bureau of Reclamation was overoptimistic with respect to crops returning high net benefits per acre.

TABLE 3

Proportions of Irrigated Crops, Madera Service Area California

Crop	1929 1	1940 2	1949 3	1951 4	1953 5	1955 6	1957 7	1959 8	1961 9	1963 10	Full development estimate 11
Cotton	34	51	39	52	38	27	21	27	28	27	23
Vineyards	30	21	17	14	13	14	16	19	19	19	13
Alfalfa	21	15	19	13	22	23	17	16	19	18	22
Irrigated pasture	2	3	14	15	16	17	18	15	13	13	21
Other	13	10	11	6	11	19	28	23	21	23	21
Total	100	100	100	100	100	100	100	100	100	100	100

Sources:

Col. 1: California Department of Public Works, Division of Water Resources, San Joaquin Valley Basin, Bulletin No. 29 (Sacramento, 1931), p. 112.

Col. 2: James F. Sorensen, "A Study of the Demand and Available Water Supply for Irrigation in the Madera Irrigation District" (unpublished Master's thesis, Department of Civil Engineering, University of California, Berkeley, 1941), Appendix Table 12.

Cols. 3-10: U. S. Bureau of Reclamation, Fresno.

Col. 11: U. S. Bureau of Reclamation, Factual Report: Madera Irrigation District, Central Valley Project, California (Fresno, 1950), p. 29.

Idem, Factual Report: Chowchilla Water District, Central Valley Project, California (Fresno, 1950), p. 24.

District Pricing Policies

The Madera and Chowchilla Districts have two major sources of revenues. The first is from tolls for water deliveries. The second is from taxes levied on the assessed valuation of land within the district. In 1960 the Madera Irrigation District priced surface deliveries at $2.60 per acre-foot. The Chowchilla District charged $2.50 per acre-foot in 1962.[1] Both districts have experimented with different prices at various times during the season to induce changes in the pattern of demand, but this has not been particularly successful.[2]

Most of the irrigators in both districts have privately owned pumping systems. These are very convenient in that water is available with the push of the electric switch, while surface-delivered water--in the seasons available--must be arranged for by telephone and permission granted to receive a specific amount of water at a particular time. The total cost of pumping groundwater is approximately $5.00 per acre-foot, 1960 prices. The variable costs of power and maintenance are only about $1.96 per acre-foot.[3] Therefore, the pricing policy of the districts is controlled by the relative cost of pumping groundwater. The district prices are actually less than the contract price of Class I water ($3.50) from the Madera Canal. The subsidy of prices and district overhead costs are met by tax assessments on land.

Taxes in both districts are levied on the assessed value of lands excluding improvements. In 1960 the Madera Irrigation District made general tax assessments of approximately $470,000 and a special assessment for repayment of a distribution system loan from the federal government of $206,000. Water tolls brought in $183,000 and other revenues, $32,000.[4] Thus, water tolls were approximately 20 percent of revenues. The revenues for the Chowchilla

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[1] A recent publication indicates that as of December 31, 1964, water tolls in the Madera and Chowchilla Districts were $2.85 and $3.00 per acre-foot, respectively. See Bank of America, San Joaquin Valley Irrigation Districts (San Francisco, n.d.).

[2] Personal communication with Messrs. Fredrick G. Bandy, Secretary-Manager, Madera Irrigation District, and H. V. Eastman, Secretary-Manager, Chowchilla Water District.

[3] Pumping cost data from Madera Irrigation District.

[4] Madera Irrigation District, op. cit.

District were approximately $390,000 of which 15 percent was from water tolls.[1] The proportion of water tolls in total revenues varies with the surface water supplies available and can be expected to increase somewhat during an average season when current distribution system construction is completed.

Drainage Problems in Madera County

One of the major causes of irrigation project failures has been ignorance of or inability to cope with drainage problems. High water tables result in water logging and increasing levels of salinity in arid areas. The developments of irrigation in the San Joaquin Valley have been accompanied by drainage problems in specific areas over time, although published warnings were available as early as 1886.[2] One of the most dramatic examples of water level buildup was in the vicinity of Fresno across the San Joaquin River from Madera County. When irrigation water was first diverted from the Kings River in 1873, the water table rose nearly 60 feet in five years. Another report from the same general area in 1909 states that land selling for $350 per acre was reduced to a value of $20-$40 per acre in 20 years as a result of drainage problems.[3]

Present indications are that there are no significant drainage problems in the two districts served by the Madera Canal. Rather, the problem is one of falling water tables. However, the valley area of Madera County slopes to the west and less importantly to the south where the river forms the boundaries. The groundwater surface follows a similar gradient but one which is less steep; that is, the depth of groundwater diminishes as the river is approached. Minimum depths of 10 feet and even less than 5 feet have been recorded near the river.[4] During the period 1946-1957, approximately 40,000 acres in the western portion of the County has potential drainage and salinity problems due to the presence of the water table within 10 feet of the surface.[5]

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[1] Chowchilla Water District, Prospectus in Connection with an Offering of $200,000 of General Obligation Warrants, 1961.

[2] University of California, Water Resources Center, op. cit., p. 21.

[3] Ibid., p. 88.

[4] Ibid., p. 81.

[5] Ibid., p. 124.

Much of the above lands are inherently unproductive due to soil characteristics. However, during the state investigations in the 1920's, nearly all the area to the west of the Madera District's boundary was classified as uneconomic for irrigation. Since the canal was completed, thousands of acres of this land have been brought under irrigation through pumping. The continued fall of groundwater levels under the Madera service area in addition to the pumping to the west has maintained favorable water levels in these areas. Natural and artificial leaching has reduced soil salinity, and importations of Madera Canal supplies have assured continual groundwater supplies. Thus, landowners to the west of the districts have enjoyed increased soil productivity and assured supplies of groundwater without bearing costs through assessments or water tolls.

Until 1965 the Madera Canal did not convey even average designed supplies and the unusually dry period, 1959-1961, resulted in increased pumping drafts within the service area. Given a series of wet years in the future, pumping drafts will diminish and infiltration of Class II water will be greatly increased. The potential exists for the spread of drainage problems, with the incurrance of considerable losses, in the areas of western Madera County which are now benefiting.

This is a further example of the costs of inappropriate boundary determination in the selection of service areas. As the situation now stands, the districts in the service area can be expected to be unsympathetic toward drainage problems to the west that may be caused by their efforts to reduce pumping costs through replenishment of the groundwater aquifers underlying the service area. Inclusion of the most productive of the western lands would have internalized the benefits subsequently enjoyed from the Madera Canal imports and created an areal base leading to a more comprehensive optimization of operations than can now be expected to take place.

One aspect of changes in groundwater gradient, in this case, is not readily considered at the planning level of Madera County. At present, the gradient along the San Joaquin River bordering the Madera Irrigation District on the south is reversed; that is, there is a net inflow from the river to the aquifers estimated at 36,000 acre-feet by the Bureau of Reclamation in 1950.[1] Further declines in the water table may well have increased this amount. Thus, the Madera District, although it no longer has water rights on the San Joaquin River, is presently receiving an infiltrated supply significantly larger than the dependable supply from the Fresno River source.

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[1] U. S. Bureau of Reclamation, Factual Report: Madera Irrigation District, Central Valley Project, California (Fresno, 1950), p. 22.

The planned operation of the Madera Canal supply system should result in the buildup of groundwater levels and the reversal of subsurface flows between the river and the district aquifers. When this occurs, downstream users of San Joaquin waters will receive increased supplies without costs in lieu of the current situation where flows are reduced without compensation. This is another externality of the Madera project.

Return Flows and Water Quality in the Lower San Joaquin River

Return flows from irrigation are generally of higher salinity levels than original sources, due to evaporation, soil salts, and fertilizers. The sources of Madera supplies are of high quality for irrigation, and the return flows are negligible at present. The development of the Madera project has nevertheless contributed in a minor way to the degradation of water quality in the lower San Joaquin Valley. This has occurred in part through the diversions at Friant and the subsequent lower volumes available for dilution of waters in the downstream segments of the river.[1]

Thus, the impact of the Madera Canal diversions has been to contribute to the reduction of the quality of downstream flows. The present low water table under the Madera District reverses the groundwater gradient and further diminishes the flows in the river. Eventually, this phenomenon will be reversed and relatively high-quality outflows will occur.

Further extensive imports of northern waters plus continued developments on east side streams will require the construction of a large-capacity drain running the length of the San Joaquin Valley. The disposal of the collected low-quality drainage waters is a subject of controversy.[2]

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[1] An extensive study of this problem was carried out by the California Department of Water Resources, Lower San Joaquin Valley Water Quality Investigation, Bulletin No. 89 (Sacramento, 1960), 189p., and appendices.

[2] In February, 1964, the Bay Area Water Pollution Control Board voted to prohibit the state and federal governments from draining San Joaquin Valley waste water into San Francisco Bay until evidence could be presented that the Bay would not be adversely affected. "Actions and Reactions," Western Water News, Vol. 16, No. 3 (March, 1964), p. 4.

Cost Structure of the Madera Supply System

The costs and revenues of the Madera supply system are incident on several groups. Within the service area, the canal, and the reservoir development at Friant, three levels are included: the federal government, the two districts served, and the district membership. As outlined in terms of the basic model, the irrigation supply flows through the federal canal to the districts where it is delivered to irrigators or to the groundwater aquifers, along with local district supplies.1/ The irrigator conveys the district supplies to the crop along with pumped supplies, and the drainage waters sink into groundwater storage for recycling from wells or flows under the western boundaries of the districts. The situation is characterized in terms of the Madera supply system in Figure 9.

At the federal level, the incident costs of developing the water supply at Friant are difficult to determine in any precise fashion because of the multiple purposes served by the Central Valley Project and the joint water supply and flood-control purposes of Friant Reservoir. The cost of Friant Reservoir was $22 million. The costs of water rights and litigation on the lower San Joaquin were roughly $4 million. The Delta-Mendota and Delta-Cross Channel Canals were in part required to exchange Delta imports for San Joaquin waters. These Canals, plus the pumping and fish-protection facilities in the Delta, cost approximately $70 million.2/ In addition, a small amount of storage costs at Shasta are properly allocated to the San Joaquin diversions because Shasta storage is needed for delivery of exchange supplies to the lower San Joaquin at Mendota.

An estimate of the total costs of the Madera supply system is not available. Moreover, any such estimate would need to be expanded to include the considerable costs of planning, interagency cooperation and disputes, and other government overhead. The costs of attaining consensus are large, as was illustrated earlier by discussions of the acreage limitation battle.

The construction cost of the Madera Canal was $3.4 million and the annual operation and maintenance costs are currently approximately $140,000.3/

1/ *Supra*, pp. 3ff.

2/ U. S. Congress, House, Committee on Interior and Insular Affairs, *op. cit.*, p. 60.

3/ Personal communication with U. S. Bureau of Reclamation personnel, Fresno, Operations Office.

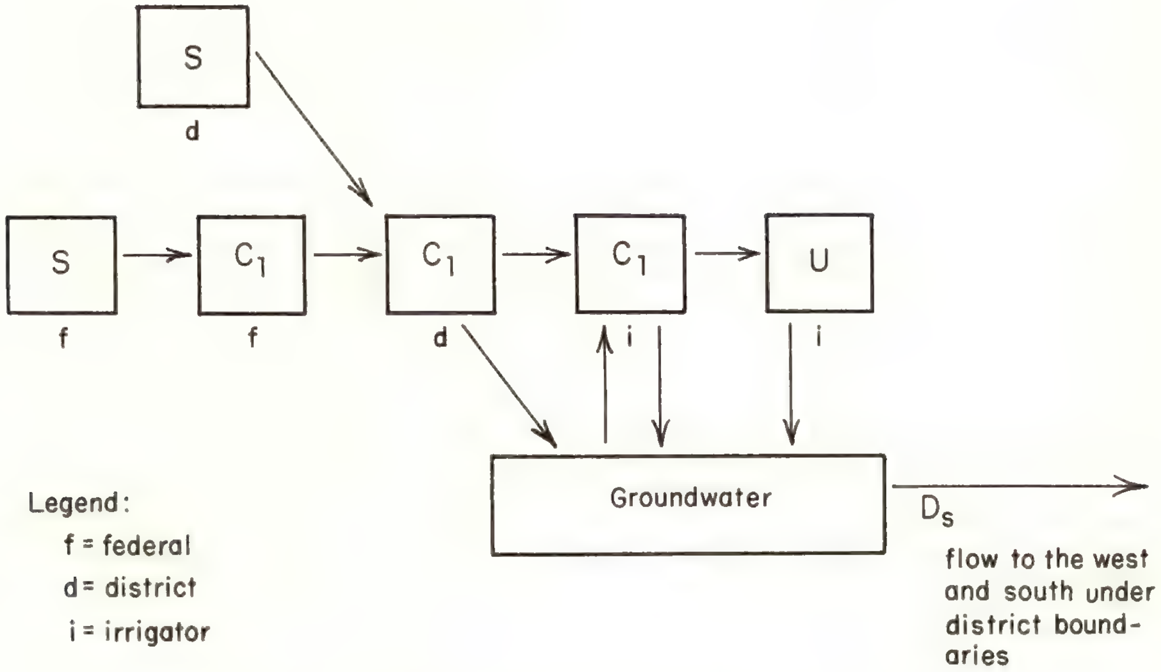

Figure 9. Schematic Illustration, Madera Supply System

The present federal pricing policy for irrigation water from Friant Reservoir is to charge $3.50 per acre-foot for Class I water and $1.50 for Class II water. Reimbursable construction costs in excess of these revenues will presumably be met from other project revenue sources; namely, power and municipal water.

It will be useful for illustrative purposes to estimate the incidence of water costs and revenues on the three principal decision-making groups in the Madera supply system. Costs for recent years have been adjusted to include the distribution system repayment and the increased overhead required to manage the average deliveries of contracted waters (Table 4).

One outstanding relationship in the estimates in Table 4 is that the revenues to the Bureau of Reclamation--that is, the charges for deliveries in an average year--constitute not more than 25 percent of the costs for water borne by the district members at the on-farm conveyance system. Further, the costs borne by the members are approximately 70 percent fixed, including both assessments on the land and the fixed costs of pumping equipment. In the short run, the irrigator may effectively select only between the alternative costs of water supplied by surface delivery versus the variable cost of self-pumped supplies which make up the remaining 30 percent, and then only during the period surface supplies are available.

An important effect of this structure is that a change in the delivery price of Reclamation water would have relatively little influence on the demands of the irrigators. Thus, a 20 percent increase in Bureau prices would result in an increase of 4-5 percent in the costs per irrigated acre in the district. Such an increase would probably be reflected in assessments and therefore would be an increase in fixed costs and not variable costs. This relationship weakens arguments that might be advanced to the effect that increased Bureau delivery prices would result in an increase in groundwater overdraft. It also weakens arguments that increases in delivery prices would create incentive for increased efficiency in irrigation use, at least in the short run. The basic facts remain that the most economic total supply management is through integration of groundwater and surface water supplies and that the control of pumping drafts remains in the hands of the landowner. The optimization of an integrated supply system requires knowledge of the cost structure and the resulting incentives for change for the water user.

TABLE 4

Madera Supply System: Idealized Cost Structure, Average Contractual Deliveries
California, 1961-62

Madera Irrigation District

U. S. Bureau of Reclamation				
Revenues:				
Class I (85,000 acre-feet at $3.50 per acre-foot)		$297,500		
Class II (87,000 acre-feet at $1.50 per acre-foot)		130,500	$428,000	
Madera Irrigation District				
Costs (annual overhead):				
Administration		$100,000		
Operations		275,000		
Loan payment		335,000	$710,000	$1,138,000
Revenues:				
Water tolls (100,000 acre-feet at $2.60 per acre-foot)		$260,000		
Assessments		878,000		$1,138,000
Irrigators				
Costs:				
Assessments	42.0%	$878,000		
Fixed pump costs	27.9%	584,000		
Water tolls	12.4%	260,000		
Variable pumping cost (189,000 acre-feet at $1.957 per acre-foot)	17.7%	370,000		$2,092,000
	100.0%			

($23.22 per irrigated acre; $7.27 per acre-foot applied)

TABLE 4--continued.

Chowchilla Water District

U. S. Bureau of Reclamation

Revenues:			
Class I (55,000 acre-feet at $3.50 per acre-foot)	$192,500		
Class II (77,000 acre-feet at $1.50 per acre-foot)	115,500	$308,000	

Chowchilla Water District

Costs (annual overhead):			
Administration	$ 50,000		
Operations	150,000		
Loan payment	150,000	$350,000	$658,000
Revenues:			
Water tolls (50,000 acre-feet at $2.50 per acre-foot)	$125,000		
Assessments	533,000		$658,000

Irrigators

Costs:			
Assessments	42.1%	$533,000	
Fixed pump costs	29.4%	373,000	
Water tolls	9.9%	125,000	
Variable pumping cost (120,000 acre-feet at $1.957 per acre-foot)	18.6%	235,000	$1,266,000
	100.0%		

($23.89 per irrigated acre; $7.47 per acre-foot applied)

(Average application, 3.2 acre-feet;[a] net requirement, 2.4 acre-feet)

TABLE 4--continued.

Alternative Calculation: Using 1949-1954 Pumping Costs

Madera Irrigation District

Irrigators

Costs:			
Assessments	47.8%	$878,000	
Fixed pump costs	20.7%	379,000	
Water tolls	14.2%	260,000	
Variable pumping cost (189,000 acre-feet at $1.676 per acre-foot)	17.3%	317,000	$1,834,000
	100.0%		

($20.48 per irrigated acre)

Chowchilla Water District

Irrigators

Costs:			
Assessments	48.4%	$533,000	
Fixed pump costs	22.0%	242,000	
Water tolls	11.3%	125,000	
Variable pumping cost (120,000 acre-feet at $1.676 per acre-foot)	18.3%	201,000	$1,101,000
	100.0%		

($20.78 per irrigated acre)

TABLE 4--continued.

a/ U. S. Bureau of Reclamation, *Factual Report: Madera Irrigation District, Central Valley Project, California* (Fresno, 1950).

Idem, *Factual Report: Chowchilla Water District, Central Valley Project, California* (Fresno, 1950).

Average irrigation requirement per acre irrigated:

Consumption use (acre-feet)	2.8
Effective rainfall (acre-feet)	.4
Net requirement (acre-feet)	2.4
Irrigation efficiency (percent)	75
Delivery requirement (acre-feet)	3.2

Sources:

Madera Irrigation District, *Audit Report for the Year Ended December 31, 1960* (San Francisco: Richard Hanlin and Co., 1961).

Chowchilla Water District, *Prospectus in Connection with an Offering of $200,000 of General Obligation Warrants*, 1961.

Resumé of the Case Study

Examination of the Madera planning, using the basic water supply model as a guide, has led to the revelation of several salient strengths and weaknesses. The central objective of the state planning was seen as economic development through the provision of irrigation water for productive soil resources which were, in part, expected to be converted to urban and industrial uses over time. The planning was imaginative and bold in concept. There was strong emphasis on the productivity and location of soil resources. Alternative major plans were investigated in considerable detail. The concept of staging development over time was a paramount consideration. Cost studies were extensively used in designing capacities of the storage and delivery structures at Friant. In short, the technical and engineering studies appear to have been of high caliber.

However, some serious deficiencies existed in the economic and financial planning of the project. Provisions for contracting arrangements, district delivery systems, district pricing policies, or drainage problems were ignored, considered unimportant, or dismissed with broad assumptions. A most serious discrepancy was the failure to consider lags in the buildup of demand for project supplies.1/

Under the federal Central Valley Project, there were costly adjustment lags in district organization and contracting, partially attributable to the 160-acre limitation controversy, which contributed to secession of the Chowchilla Water District, delays in the construction of district delivery systems, failure to deliver full potential supplies, and loss of revenues to the federal government.

The Madera Irrigation District followed a policy of exclusion to reduce the marginal lands to be served by the distribution system and possibly to reduce dissention within the district through exclusion of dissentors. Later developments of irrigation outside the boundaries of the district indicate that the exclusion policy was carried too far to maintain control over groundwater pumping. However, under current conditions, the formation of a super

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1/ The last block of supply from Friant Reservoir was only recently contracted. This is a lag of 20 years following construction. "Actions and Reactions," Western Water News, Vol. 16, No. 3 (March, 1964), p. 4.

district including both the Madera and Chowchilla Districts and other lands in Madera County is a possibility. Such a district could act as a contracting agency for conveyed supplies from the proposed East Side Division of the Bureau of Reclamation.[1]

Large new projects are to some extent experimental, and the viewpoint of the present does not allow an unbiased evaluation of whether the above criticisms are fully justified in light of the conditions prevailing at the time. They do, however, indicate problems to be faced and consequences to be avoided in the future. Two external effects of the project cannot be realistically considered relevant or foreseeable during the planning period. They are the intensified problem of mosquito control and the destruction of the San Joaquin salmon fishery.[2] These are now considered as important issues.

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[1] Madera County has been included in the potential service area of a supply system conveying water from the American and Sacramento rivers south to Kern County, paralleling the Madera Canal but flowing in the opposite direction. U. S. Bureau of Reclamation, East Side Division, Central Valley Project, California: A Report on the Feasibility of Water Supply Development (Sacramento, January, 1962), 79p.

[2] U. S. Congress, Senate, Hearings Before the Senate Select Committee on National Water Resources, 86th Cong., 1st Sess., 1960, S. Res. 48, Part 5, p. 773: "Widespread irrigation usually results in difficult mosquito control problems unless an adequate drainage system is provided to accompany each water distribution system. The public health importance of mosquito control was graphically shown by the outbreak of mosquito-borne encephalitis in the Central Valley of California in 1952, with over 800 laboratory-proven cases and 52 deaths" (statement by E. E. Reinke, Chief Sanitary Engineer, California Department of Public Health).

Ibid., pp. 858-876 (statement by William Warne, Director, California Department of Fish and Game).

SUMMARY AND CONCLUSIONS

The initial objective of this study was to develop a simple comprehensive model representative of water supply systems. The basic components include a point of source development, a conveyance link, a point of utilization, a second conveyance link, and a point of disposal. The next step was to include empirical relationships common to water supply systems.

Considerable emphasis has been given to adoption of a comprehensive view of all basic components and relationships of the system. For example, the source development and conveyance link are often interrelated. The drainage links are usually related to the utilization and initial conveyance components. The quantity, quality, and timing of water disposal from one system have potential impacts on sources for other systems, and so on. The objective in adopting a comprehensive viewpoint is to internalize costs and benefits otherwise appearing as externalities to the system. Through internalization of costs and benefits, the optimization process raises the design of the system to a higher level of efficiency than would otherwise result.

The planning problem has been considered as a process of linking demands for water to supplies through a conveyance system. This is essentially a market analysis problem with water conveyed in a locational and temporal sense to consumers. The market or service area is defined as including those consumers who would purchase water from the system at the costs necessary to deliver it to them.

The planning process should be viewed as iterative because of the interrelationships between basic components of the system and the economics of size in constructing and operating system components. For example, the quantities of water demanded are dependent on the prices of supply, and the costs of supply are dependent on the size of the system required. Therefore, the process of planning should proceed from crude assumptions initially, through successive iterations of increasing refinement, to the final design. Such a process requires a free flow of information and cooperation between specialists and specialized planning groups at successive stages during the period of planning.

The difficult problem of planning under uncertainty has been explored to a limited extent. The use of projections and the incorporation of flexibilities are directly related to the conceptual framework of planning reviewed briefly above. The role of the contracting process for vendible services has been viewed as an activity complementing the planning process by yielding useful data for the concluding stages of design.

Limitations of the Conceptual Approach

The conceptual approach is heavily dependent on the ability to determine basic economic relationships and the unrestricted substitution of resources, although the spatial pattern of water and land resources is, of course, given initially. The objective of design is to maximize net benefits to the area of impact of the system.

These assumptions must, at least partially, be relaxed in most empirical situations. Current water supply developments are increasingly complicated by hierarchies of decision making. The case studied revealed three levels of decision making--the wholesaling agency, the retailing agency, and the water users. The economic behavior of the ultimate consumer, with respect to water use, can be realistically estimated only by evaluating the price policies of the intermediate district and the economic alternatives available to both the district and the consumer. The evaluation of cost structure for the Madera service area indicated that significant changes in Bureau pricing policies would probably have relatively slight impact on water use. In other systems, such as the Metropolitan Water District of Southern California, the hierarchy of decision levels is even more complicated.1/

The policies of public organizations are generally much broader than the efficiency objective. The objectives of public agencies have been characterized as being cooperative in nature and concerned with equity as well as efficiency. It has been further asserted that we may expect the optimization of multiple objectives to be in the interest of the public that actually interacts to reveal the objectives, that is, the district membership.

The fragmentation of resource control, primarily water rights and the boundaries of the organization, creates immobilities of resources and potential

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1/ The Metropolitan Water District of Southern California, Water for People: An Outline of the Metropolitan Water District Aqueduct from the Colorado River (Los Angeles, 1960), 14p.

Leonard, *op. cit*., p. 78.

service areas that restrict substitution and constrain optimization. These conditions may be expected to result in the optimization of the system design at lower levels than is visualized conceptually. District boundaries may be changed and water rights may often be purchased or acquired through "eminent domain" process. The case study revealed that both have taken place under the Central Valley Project. Institutions may be expected to be flexible over time but the change is not automatic. Changes require both political and economic power. The tangible costs of court actions, negotiations, and purchases are seldom made fully explicit. The intangible costs almost never are.

The importance of comprehensiveness has been stressed throughout the study. This concept must be bounded realistically in some way because in an unrestricted sense the impact of a project reverberates throughout the economy. Actually, the focus in this study has been on the immediate effects of each of the operations of the model. We have not been concerned, for example, with the marketing facilities for irrigated production or the social overheads required for growing population. The choice of the level of comprehension is a matter of judgment based on the objectives of the development and the planning resources available. If the objective, for example, is national or regional economic development, water supply is only one of a large number of alternatives that should be considered.

In practice, the level of comprehension including all the immediate impacts from the system may not be attained when, for example, the costs of drainage and disposal are incident on other groups and the developing agency or district is unwilling or unable to take externalities into account in a satisfactory fashion. In other words, the operations of the supply systems are under the control of different groups. This is true of the current controversy over the location of San Joaquin Valley drainage facilities. In this case, both federal and state agencies are to be found on both sides of the issue.

Actually, in the case of state and federal planning on the Central Valley Project, the planning agencies had extraordinary freedom to adopt a high level of comprehensiveness. The objective was basically irrigation development, and the system was a truly regionwide supply system. The California Water Plan is similar in scope, although advances in technology have increased the potential service area to include southern California. Much of the water supply planning for smaller projects has a much more restricted potential for the comprehensive viewpoint, and the coordination between operations is relatively more costly.

General Applicability of the Approach

The strengths of simplicity and comprehension of the conceptual approach have been emphasized and the empirical limitations have been discussed. The question remains: Does the conceptual approach have a significant potential for the improvement of planning for water supply? It does. The central consideration is the demand for water.

Whether expressed in the market or the political process, the provision of supply requires the use of resources that have opportunity costs. The choices necessary for resource allocation will be based, in some fashion, on relative demands.[1] It is expected that there will be continuing pressures for systematic and comprehensive planning along conceptual lines.

Another optimistic sign is the growing professionalism and variety of disciplines represented on planning staffs. As agencies and districts grow in size, their ability to carry out comprehensive studies and necessary complementary research also increases. The growth of planning staffs increases problems of internal coordination. But the accompanying rise in professionalism, it may be hoped, will increase the desire to put planning on a systematic and sound conceptual basis because the responsibility for the bulk of the low-level and incremental design decisions will be given increasingly to the planning groups.

The incentive for the policy groups to adopt a comprehensive viewpoint in water supply development, in addition to their sense of public responsibility, is the operation of the concept of "countervailing powers." Water users, water agencies, and districts are becoming increasingly organized. The growth in financial and political power makes water development conflicts increasingly costly. The adoption of a comprehensive viewpoint and consideration of all aspects of the water supply system promise to reduce the costs of consensus between affected groups and to point the way to mutually beneficial compromise. A system "designed" by bitter controversy can seldom be expected to be optimum from any point of view.

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[1] Stephen C. Smith, "Population Demands for Land and Water Resources of the Hinterland," in Wynne Thorne, ed., Land and Water Use, American Association for the Advancement of Science, Publication No. 73 (Baltimore: The Horn-Shafer Company, 1963), pp. 25-44.

Vernon W. Ruttan, The Economic Demand for Irrigated Acreage: New Methodology and Some Preliminary Projections, 1954-1980, Resources for the Future (Baltimore: The Johns Hopkins Press, 1965), 139p.

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